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Automated in-row weed trimmer

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SANTA CLARA UNIVERSITY

Department of Mechanical Engineering

I HEREBY RECOMMEND THAT THE THESIS PREPARED
UNDER MY SUPERVISION BY

Joshua Baculi, Tyler Castrucci, Joshua Ding, Marit Knapp, Gaston Young

ENTITLED

AUTOMATED IN-ROW WEED TRIMMER

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AUTOMATED IN-ROW WEED TRIMMER

By

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SENIOR DESIGN PROJECT REPORT

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ABSTRACT

The Automated In-Row Weed Trimmer, or AIRWT, is a weed removal system designed to be used in vineyards in order to enable safe and efficient removal of weeds while preventing damage to the vines. The goal of the system is to reduce the need for the use of manual labor and herbicides while improving production rates of grapes by automating the weed removal process at vineyards. By implementing an automated system for weed removal, the team aims to resolve ethical issues in food production, primarily those surrounding human labor, environmental friendliness, and social sustainability. The focus of this report is to explore in depth the AIRWT system concept as well as its subsystems, in addition to reviewing its product development cycle.

Keywords: Automated hillside weed trimmer, Edison microprocessor, in-row weed removal.

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Table of Contents

List of Figures

Chapter 1

Introduction

1.1 Background

Weeds in organic vineyards compete with crops for water and nutrients; they are additionally expensive and labor-intensive to remove. An automated weed removal system would reduce the need for the use of manual labor and herbicides while improving crop production rates. Non-organic vineyards utilize chemical methods (such as herbicides) to deal with weeds. These methods are a more cost and time effective means of dealing with weeds compared to current non-chemical methods (such as hand hoeing, cultivating, and mowing) due to the simplicity of its execution. With herbicides, a vineyard owner can quickly make rounds through the rows, spraying in general vicinities with confidence in the method's thoroughness. In addition, spraying is much less manually taxing than pulling out the weeds by hand as all that needs to be done is essentially point and shoot. This allows herbicides to be used in a variety of terrain, such as hillsides, where a worker rather than a whole vehicle can simply walk down the row spraying.

However, automated devices are also beginning to play an increasingly larger role in society. By implementing automated solutions in the agriculture industry, these devices will address several societal and ethical issues, including meeting the demands of an ever-increasing population, reducing the need for intensive human labor, and limiting negative environmental impacts for increased sustainability.

Figure 1.1: An example of how serious of a problem weeds can become in vineyards. Image open sourced from http://a-la-recherche-du-vin.typepad.com/rouge_bleu/ without permission.

1.2 Literature Review

While research on technology for weeding in the agricultural industry exists, there was little research specifically on automated in-row weeders and even less on hillside weeders. Therefore, the team approached this project through general research of techniques used to weed vineyards and focused on automated technology used in the agriculture industry. Starting from a broad overview of weeding in vineyards and narrowing the focus to specific technologies used for weed removal, the team's research helped to discover what has been done in the past, what methods were being implemented, and how the project would proceed.

In addition to herbicides and mulching, the combination of in-row line cutting, tilling, and cultivation had been a method of weed suppression for some time. Results of this has suggested that

Figure 1.2: The kinds of heavy-duty sprayers used for removing weeds in vineyards. Image open sourced from `https://encrypted-tbn2.gstatic.com/images?q=tbn:ANd9GcTHH2zhg3UsbfaJ9efhJEYHMrZ0RIMpqTr5jCc_LMGpyL8KDmns` without permission.

twice-yearly row cultivation resulted in a comparable yield to herbicide spraying and mulching, with all having a significantly higher yield than a control. However, it was found that these methods had only been performed successfully on flat terrain; on a hillside, tilling and cultivation encourages ground erosion, mulching has a tendency to fall down hill. On top of this, certain herbicides are not allowed for an organic farm, and it is likely because of this that no studies were found regarding the optimal method for organic hillside weed removal. After researching some case studies, the team realized that the real challenge to creating an automated weed removal systems would be distinguishing the weed from the crop. The team decided to utilize a discriminate weed identification method, one that would identify weeds individually, in order to ensure accuracy of the device. Based on the previous studies, it was determined that the team would be best suited utilizing an Arduino with a task-based approach for a controller.

”Down On the Robofarm” explores how autonomous robots, or agribots, can and should be applied in agriculture. Crow claims that these robots will need to be able to do three things: navigate, interpret the farm, and help the farmer through weeding, applying chemicals, or harvesting.[1]

The team's research showed that the real challenge to automated weed removal systems has been distinguishing the weed from the crop. It was also discovered that weed elimination would greatly impact the production of several types of crops and would lead to less of a need for herbi-

Figure 1.3: An illustration of the kinds of slopes vineyards are grown on. Image sourced from `http://www.lonelyplanet.com/travel-blog/tip-article/wordpress_uploads/2013/09/Vine.jpg` without permission.

cide.

Crow provides his solution to getting rid of the weeds: a weed laser gun. This article sites the use of vision systems as the detections method. There are a number of different developing technologies discussed that are being used to automate the agriculture business, and this leads to the discussion on the effects of added technology. According to Crow, labor is one of the largest costs in farming, on average forty two percent of production expenses on US farms are spent on labor. Potentially, the development of a system used in the vineyard could be adapted for other crops. This source highlighted the opportunity and business potential of creating a device that would be applicable to such a large market. This source was found on EBSCO Host, through the Santa Clara University Library website.

Practical Arduino [. . .][2] was a book that the team considered using in order to learn more about basic program with the Arduino. Although the team hoped to use an Edison to implement the project, it was expected that learning how to interface with a microprocessor like Arduino would allow the team to familiarize and easily switch to the Edison when it arrived. The team also needed to learn how to use the Arduino language with a practical, task-based approach, how to communicate with various complicated decoding, and how to connect and use the hardware and integrated circuits with the Arduino.

This book runs through projects, including: home automation, automotive, communication, and instrumentation, which was relevant to the project programming needs. This source also provided information on how to communicate with sensors, GPS modules that connect the Arduino to WiFi, and much more complicated decoding. Most importantly, the book focused on learning how to connect and use the hardware and integrated circuits with the Arduino. Getting experience in building an automated system and testing it before the prototype was built was very important, so the skills learned from projects done in the book were thought to be vital to the success of our programming and controls system. This book was suggested to the team by an electrical engineer working for Insitu, Inc. and the team looked more into the specific projects it teaches online.

Found in the EBSCO Host database, Laser Zentrum Hannover and Leibniz Universitat Hannover's Biosystems and Horticultural Engineering faculty[3] developed a robot that can zap weeds. The robot employs a laser system that uses 35 Joules of energy to kill individual weeds. Weeds are identified through a stereo camera system that positions the laser with respect to the weed. In greenhouse conditions, the robot had an accuracy of +3.4mm. According to the article, the robot is able to go from plant to plant quickly, however, not many specifics were given. Initial results lead scientists to believe that these weed killing robots could be released on large farms, enabling them to sweep fields and kill weeds individually.

This article was not as helpful as anticipated because it did not give hard data on the capabilities and performance of the robot. Additionally, more information on how the stereo camera detected and identified weeds from crops would have been of interest to the team. The team decided to utilize a discriminate weed identification method, one that would identify weeds individually.

Weigle and Carroll's production guide[4] to growing organic grapes was cited on Washington State University's Viticulture and Enology page listed under Organic Vineyard Management.

The report gives extensive discussion in many areas of vineyard management focusing on cultural and pest management practices. Although the report covers topics that have an impact on improving plant health and pest prevention, the source recognizes that there are limited pest management products available for use in organic farms. There is an entire section on weed management and the report goes into the specifics of the importance of in-row weeds. Although the majority of the report is not on weeding of vineyards specifically, the section on weed management heavily stressed how in-row weeds affect the production of grapes. not only during the spring and winter, but throughout the summer, and critical during bloom until veraison. There are specific cultivation depths given for in-row weed management.

It was determined that in-row weeds must be reduced because in addition to improving production, removing the weeds would also help with rodent control.

1.3 Project Objectives

The Automated In-Row Weed Trimmer (AIRWT) seeks to reduce the need for manual labor and herbicides while improving production rates of grapes by automating the weed removal process at vineyards. By implementing an automated system for weed removal, the product aimed to resolve ethical issues in food production, primarily current problems surrounding human labor, environmental friendliness, and social sustainability.

The original project specifications, as defined by the customer use case, required that the final prototype achieve the following:

- Attain comparable performance levels to flat-plane weed removal mechanisms when functioning on sloped/terraced vineyards
- Function completely under electric power sourced from environmentally friendly resources
- Propose a significant value proposition compared to competitive products
- Achieve true fire and forget (fully autonomous) functionality, and perform consistently without the need of supervision

- Remain adaptable for different environments including but not limited to different terrain, elevations, weather conditions, and vineyard sizes

Arguably the most important functionality of the AIRWT system is its ability to perform consistently on sloped and terraced environments. At the start of this project, there were no mechanical systems, automated or otherwise, that could perform weed removal on sloped environments. The closest competitors to the AIRWT system were conventional automated in-row tillers and mowers, which could only operate on flat land. By focusing on the ability to function in sloped and terraced environments, the AIRWT presented a large value proposition to vineyards by offering a two-in-one weed removal solution.

In addition, conventional automated in-row tillers and mowers required significant capital and operating expenses to run. As a result, this left only the most well-established of vineyards able to afford the operation of such machinery, putting smaller vineyards at a significant disadvantage.

At the largest disadvantage are organic vineyards, which are barred from using herbicides as a weed removal method. As a result, small organic vineyards are constrained to resorting to manpower to remove weeds, which is both a time-consuming and labor-intensive process; any time focused on weed removal for these vineyards is time lost to other vital activities, including infrastructure development and crop management.

With these constraints in mind, the AIRWT was designed with small organic vineyards as a primary user base. Noting that an increasing number of startup vineyards are turning to organic farming methods, AIRWT provides a cost-effective, scalable weed removal solution that eliminates the need for herbicides and manpower. This furthers AIRWT's value proposition, and separates it from the competition as a cutting-edge, environmentally-conscious food production solution.

Given the nine month time frame of the project, this iteration of the AIRWT system served as a proof of concept of the retraction/extension mechanism on sloped terrain. The autonomous vehicle and cloud based system that would allow for fully autonomous functionality are features that will be added during future iterations of the project. The fully autonomous vehicle would most likely be an existing RSL rover that the AIRWT system can simply be mounted on. The vehicle's path would be controlled by a cloud based app that the user can simply setup once on a smartphone. These two features are beyond the scope of this project in both time and engineering knowledge as they are more electrical engineering based.

With the previously mentioned limitations in mind, the main goals for this proof of concept iteration now become:

1. Attain comparable performance levels to flat-plane weed removal mechanisms when functioning on sloped/terraced vineyards

2. Function completely under electric power sourced from environmentally friendly resources

3. Propose a significant value proposition compared to competitive products

By the end of the project's timeline, as shown in Appendix J, this iteration of the AIRWT system was only able to accomplish goals 2 and 3. Goal 1 has theoretically been achieved but time constraints and unforeseen mechanical limitations, which will be discussed later on in this report, prevented actual sloped testing.

Chapter 2

Overall System Integration

2.1 System Overview

Appendix Figure N.1 shows a graphical representation of the AIRWT system. Labeled are the major components. The connections represent how the components interact with each other. Green connections represent signals coming out of the microprocessor or power supply. Orange connections represent signals coming into the microprocessor.

2.2 System Level Requirements

Based on market segment needs, the team determined the following system requirements to be explored in the design process:

1. Development of the AIRWT as a *standalone system*, meaning that the system functions without the need of a tractor and power take-off unit

2. An automated weed removal mechanism

3. System functionality on sloped/terraced environments

4. An electric power source

5. Adaptable mounts for scale-up/scale-out opportunities as well as adaptation for different agriculture sectors

6. Maintain a system cost of under $2,500

2.3 Functional Analysis

Given the system level requirements, the AIRWT system was developed with the following seven key components:

1. Retraction mechanism
2. Weed removal attachment
3. Mounting vehicle
4. Sensor
5. Microcontroller and supporting electronics/software
6. Main housing

The *retraction mechanism* facilitates the lateral movement of the device. Paired in conjunction with the sensor, microcontroller, and supporting electronics/software, the retraction mechanism enables the safe removal of weeds and prevents any harm to the vines.

The *weed removal attachment* serves to trim the weed during the operation cycle (per request of the customer), and draws power from the onboard power source.

The *mounting vehicle* consists of a push cart with a wooden deck affixed to it, and provides the base on which all other components are attached to.

The *sensor* is attached externally to the housing, and protrudes a certain distance from the edge of the device. If the sensor makes contact with a vine during the cultivation process, then it will detect resistance and work in conjunction with the retraction mechanism, microcontroller, and supporting electronics/software to facilitate movement of the retraction mechanism in such a manner that will enable the safe removal of weeds and prevent any harm to the vines.

The *microcontroller and supporting electronics/software* are used in conjunction with the retraction mechanism and sensor to facilitate movement of the retraction mechanism in such a manner that will enable the safe removal of weeds and prevent any harm to the vines. Software for the microcontroller has been developed so that it will receive sensor resistance as input, and output movement commands for the retraction mechanism. In addition, the electronics subsystem include all power sources to supply power to both the cutting tool and electronics.

The *main housing* serves as an enclosure for hosting all subsystems as well as provide an attachment point for those subsystems that will be mounted externally.

A functional flow block diagram of this device may be seen in Figure A.1 of the Appendix.

2.4 Customer Needs

The AIRWT team's customer owns a small organic vineyard; a majority of which vineyard rests on a hillside. When consulting this customer, the three most paramount design requirements were determined to be

1. Fully or semi-automated weed removal system
2. Weed removal via trimming
3. System functionality on sloped/terraced environments.

Currently, the customer hires a team of seven workers, paid at a rate of $15 an hour, working for eight hours a day for two to three weeks on end. By automating the trimming process, herbicide use and manual labor expenses could be greatly reduced.

For this initial use case, the team considered the use of the mechanism itself, and did not integrate it with an autonomous vehicle as depicted in Figure 2.1. Ideally, the operation of the mechanism will be observed by a skilled operator or foreman, who will have the ability to cease operation of the device via the emergency kill switch.

2.5 Benchmarking and Competitive Analysis

The existing competition for the AIRWT ranges from semi-autonomous joystick-controlled rotary tillers to fully automated solutions. Competitive products that have a fully automated retraction subsystem, like the Kimco Manufacturing Model 9300 and Pellnec Tournesol, are extremely

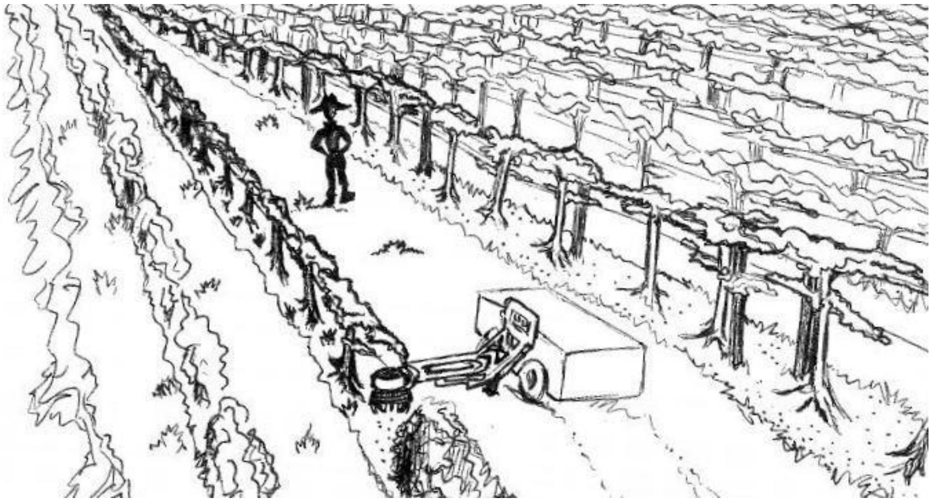


Figure 2.1: Artist's impression of a concept AIRWT system in operation on a vineyard.

costly, and may be priced upwards of $20,000. Even less costly semi-autonomous solutions like the WeedBadger Model 4000 and the Falconero Frese carry MSRP's of more than $6,000 new. Furthermore, all of the aforementioned solutions require a diesel-powered tractor and power take-off unit to operate, introducing even more operating costs.

Such pricing places these units out of reach for many small vineyard owners; as a result, they are not able to remain competitive with larger operations. Moreover, the introduction of a tractor and power take-off unit will only aggravate the situation for small vineyards, as owners must now account for the additional operating expenses for fuel and maintenance. As a result, the team has placed a cost cap on the AIRWT system at $2,500 to create a segment-leading value proposition.

From a sustainability perspective, all existing solutions are leaving a largely negative impact on the environment as the reliance on a tractor only means more emissions (and thus aggravating pollution). Currently, the AIRWT system is the only fully electric and near zero-emissions system.

This is a near zero-emissions system because the only pollution the AIRWT generates are residual emissions from the power plant that the system will ultimately draw power from (to recharge the batteries). However, the team's ultimate vision is for a fully green solution, with the system drawing power from renewable sources (i.e., wind, water, solar).

Furthermore, the AIRWT system is currently the only semi-autonomous or autonomous system to whose goal is to function on sloped/terraced environments and in tight spaces. All of the AIRWT's competitors function solely on flat-lands as they are designed with very limited mobility; the sheer bulk of these systems also prevent proper operation on smaller vineyards as well.

The datum the team intended the AIRWT to achieve or surpass can be found in the PDS in the Appendix.

2.6 Performance Optimization

The primary system performance characteristics to be optimized are the accuracy and seedling spread, followed by the weight, fuel consumption, and the cost. Seedling spread is the scattering of the weed seeds due to the rotation of the cutting head. To ensure that the weeds are thoroughly removed, the AIRWT system must achieve high accuracy rate; the accuracy rate will be benchmarked against a human worker (who will completely treat an area of weeds).

During initial research, the team determined that seedling spread appeared to be an important factor dictating system accuracy. However, upon further discussion with the customer, the team determined that seedling spread was not an important factor in the design of the system.

The concept scoring of the proximity sensor shown in Appendix A, Figure A.1 indicated that using a sensor arm would be the most viable for this subsystem due to its quick and easy design. While the visual and thermal recognition sensors have comparable accuracies, their complexities would have severely restricted the progression of the product development cycle.

The higher speed weighting shown in Figure A.5 contrasts with the lower speed rating of the overall system shown in Figure A.1. This is because having a slower sensor would greatly prolong the overall execution time, enough to make the AIRWT too inefficient.

The retraction mechanism subsystem will facilitate the lateral movement of the device. Paired in conjunction with the sensor, microcontroller, and supporting electronics and software, the retraction mechanism will enable the safe removal of weeds and prevent any harm to the vines; this dictated a need for a highly responsive retraction mechanism as any harm to the vines would defeat the purpose of the AIRWT system. The responsiveness should prevent any contact between the system (other than the sensor arm) and the vines.

Next in importance for this device is the speed and response time of the retraction mechanism; the faster the system is able to perform a single extension/retraction operation, the faster the system will complete one cycle of operation.

By ranking the relative importance of a set of criteria, evaluation of different power supplies was analyzed. The majority of the power will be used to drive the weed removal mechanism and linear retraction mechanism. An ideal power supply would be light, cheap, and supply sufficient power to the system. The most important criterion of the power supply was that it was able to provide the power necessary to drive the system. A light-weight power supply would help with the overall design of the device because a lighter overall design will perform better on steep slopes. To make our design competitive to others in the field, minimizing costs is essential. The pollution during operation would ideally be minimized, although the unit is small, so environmental effects would be minimal compared to the large tractors that are operated on flat terrain. Any extra equipment or fuel necessary to operate the power supply was considered to be a slightly negative factor because it would take up space and weight. Noise was not considered an important factor to base the selection of the power supply because the device will operate autonomously, far from humans.

2.7 System Options and Trade-offs

The final specifications achieved in the AIRWT prototype were a result of several trade-offs during exploration of system options. These decisions were made primarily in light of the design restraints of timing, cost, product vision, and customer requirements.

2.7.1 Timing

In any product development cycle, timing is often a large constraint when it comes to creating a go to market solution, and a nine month product development cycle placed certain restrictions on product scope of the the AIRWT system. The team determined early on that the development and integration of an autonomous mounting vehicle with a robotic weed removal mechanism was not achievable in this timeframe. As a result, the decision was made to utilize a manual push-cart as the mounting vehicle so that the team could concentrate on developing an effective robotic weed removal system. However, this does not impact the system's operating cost, as a fully automated system requires a human supervisor during operation as well.

2.7.2 Cost

A budget of $2,500 placed severe limitations on how the team sourced its parts and manufactured its components. Coupled with a tight time constraint, the team deemed it best to acquire as many off the shelf parts as possible. This not only reduced cost, but also kept time spent in custom fabrication to a bare minimum and ensured proper fitting of components, as the team utilized a variety of standard components.

The budget also dictated the need for several trade-offs around the retraction mechanism. Early in the concept generation process, the team explored the use of gearing and hydraulic components to achieve cutting implement extension/retraction. However, noting the high cost of these components, the team decided to pursue the most cost-effective solution of using a linear actuator, which could also be paired with off the shelf mounts, supports, batteries, and so on.

2.7.3 Product Vision

During concept generation, the team also explored the possibility of using a small gas engine coupled to a power take-off unit as a power source for the AIRWT system. However, upon further examination of the product vision for an environmentally-sustainable system, the team elected to use rechargeable batteries as the system's power source.

Furthermore, the product vision of an *autonomous* system required the use of a sensor system. The team examined several options, including optical methods; however, to reduce complexity and cost as well as achieve a faster go-to-market time, the team elected to implement an electromechanical force sensor with a beam and potentiometer.

In addition, the product vision for an adaptable system dictated the need for easily removable mounts in order to attach linear actuators and cutting implements of different sizes and types.

2.7.4 Customer Requirements

The team's customer requested that the system remove weeds via trimming. As a result, the team did not explore cultivator and tiller attachments for the AIRWT system. Instead, the team was able to adapt an off the shelf electric weed whacker for this particular application. This reduced both cost and time spent in custom fabrication; included with the weed whacker was a rechargeable battery, which the team integrated into the prototype.

The customer also requested that the system function on a sloped/terraced environment. This resulted in the team designing a 3 degree of freedom plane system utilizing several pivot points on the system to achieve maximum mobility, especially at flat to sloped transition areas.

2.8 Risks and Mitigations

The inclusion of any destructive device in a system always dictates that the proper safety measures be taken to prevent any unintentional harm. The obvious destructive device in this system was the cutting tool. The team was and still is committed to safe and proper handling of this subsystem during assembly and thus chose to completely enclose the cutting tool in this design to prevent the possibility of an accident during operation.

A secondary concern was unintentional harm to the vines. If the sensor happened to fail without warning, then the system could have damaged the vines. In light of this possibility, the team elected to include a manual override switch to prevent the possibility of unintended crop damage. The switches consisted of two flip switches, red for the cutting head and blue for the linear actuator. In addition to these two flip switches, an E-stop push button was implemented to cut the power to the entire system, cutting head and linear actuator in all.

2.9 Timeline

The complete timeline for this project may be reviewed in the Appendix G. Anticipated time issues included the ordering of parts, which were expected to require several weeks of lead time if being shipped from overseas. While the team made every effort to source locally available parts, ultimately the product development budget dictated where the parts were obtained.

During planning for the product development cycle, the team reserved at least two weeks of development time to test the concept system with the primary customer. Once testing was complete, team had some time to make improvements on the performance of the system in light of the datum collected during testing.

2.10 Design Process

The AIRWT project followed a traditional market-pull product development process, meaning that a customer need dictated the design and development of the system. The ”front-end process” of this cycle may be broken down into the following steps:

1. Identifying customer needs
2. Benchmarking of competitive products and economic analysis
3. Establishing target specifications
4. Concept generation
5. Concept selection
6. Concept testing
7. Setting final specifications
8. Development/refinement of prototype
9. Testing and evaluation of prototype

2.10.1 Identifying customer needs

The first step of the product development process, and perhaps the most vital, was determining the customer use case and requirements. As discovered, the team's customer had several particular requirements somewhat unique to his vineyard.

2.10.2 Benchmarking of competitive products and economic analysis

Knowing the customer needs, the team began to explore what was currently available to the customer to use, as well as performing a cost-benefit analysis on each available solution. As no product on the market today was able to achieve the customer's requirements, the team found an opportunity to develop a new product.

2.10.3 Establishing target specifications

Immediately, the team was able to set several qualitative target specifications, including the capability to function on a sloped/terraced environment and a sub $5000 price point. After re-examining the customer needs and the team's mission statement, more target specifications were set including the need for a rechargeable battery, retracting arm, and sensor system.

2.10.4 Concept generation

After establishing the target specifications, the team explored several system concepts, which included different systems of retraction, various mechanisms for trimming, and several methods of force sensing.

2.10.5 Concept selection

The team then proceeded to examine all concepts, and rate each system based on feasibility, cost, and weighted importance of certain target specifications. This selection process was repeated until all but one concept was eliminated from the pool.

2.10.6 Concept testing

The selected concept was then tested against the target specifications to determine whether it could adequately achieve the desired levels of performance. Where the team deemed the concept system lacking, components were revised and improved; in addition, several system options were explored and trade-off analyses were performed, leading to the development of the final specifications

2.10.7 Setting final specifications

Based on the revised and improved concept, the team set its final specifications and compared it to the target specifications. Deeming the final specifications to be within acceptable range of the target specifications, the team proceeded to design, manufacture, and source parts for prototype assembly.

2.10.8 Development/refinement of prototype

After determining the final specifications and design requirements, the team proceeded to design and develop a prototype. In this stage of the development cycle, several adjustments were made to the system to enhance mobility and usability.

2.10.9 Testing and evaluation of prototype

Upon completion of prototype development, the team proceeded to perform testing and evaluation of the system to determine how closely the AIRWT was able to match the final specifications and the target specifications. The development/refinement and testing/evaluation process was an iterative one, as the team made improvements in areas that weren't immediately within the target specifications.

2.11 Team and Project Management

The team ensured that the delegation of duties was fair and even; all projects and deliverables were viewed as collaborative efforts, with the expectation that all team members would contribute and assist in driving the project to a successful resolution. Activity reports were completed at the end of each week to judge each team members performance and level of involvement in the project; any notable disproportionality in team members hours vested into the project were subject to review by the teams managers and the team managers could have elected to leverage penalties or increase the workload(s) of the offender(s).

The product development team's terms and conditions may be observed in Figure O.1.

2.12 Team Member Roles

Joshua Baculi was one of the co-leaders of this team and primarily worked on the product design for the AIRWT project, as well as the dynamics and control aspects of the project.

Gaston Young was the other co-leader of the team who is working towards a 5-year BS/MS with a controls and dynamics emphasis, and as such primarily worked on the mechatronics and control aspects of the AIRWT project.

Tyler Castrucci lead FEM simulation analysis for the AIRWT system as well as assisted in mechanism design. In addition, he brought valuable knowledge of vineyards to the team as his family owns Castrucci Vineyards.

Joshua Ding has a strong emphasis in mechanism and product design. After taking MECH 275, hes experienced a three month product development cycle and brought valuable product design expertise to the team on top of his software development experience. In addition, Joshua enrolled in the 5 year BS/MS program with an emphasis in Mechanical Design.

Marit Knapp has experience in robotics and has worked in the prototyping lab of a small Unmanned Aircraft Vehicle company. She has a strong emphasis in mechatronics as well as controls systems and was one of the lead designers for the sensor system.

Chapter 3

Retraction Mechanism

3.1 Subsystem Overview

The retraction mechanism subsystem facilitates extension and retraction of the weed removal attachment subsystem; it interfaces with all electrical and mechanical subsystems in the AIRWT and physically conjoins the mounting vehicle subsystem and weed removal attachment subsystem.

3.2 Subsystem Components

The retraction mechanism subsystem consists of the following components:

1. Linear Actuator (red arrow)

2. Retracting arm mount (blue arrow)

3. Elevated base mount (green arrow)

3.3 Subsystem Options and Trade-Offs

3.3.1 Linear Actuator

During initial concept selection, the team explored options of gearing systems and hydraulic components to achieve extension and retraction. However, in depth analysis revealed the high cost and intricate complexities of such systems; furthermore, the time constraint preventing the team from developing a gear or hydraulic-based extension/retraction mechanism. As a result, the team

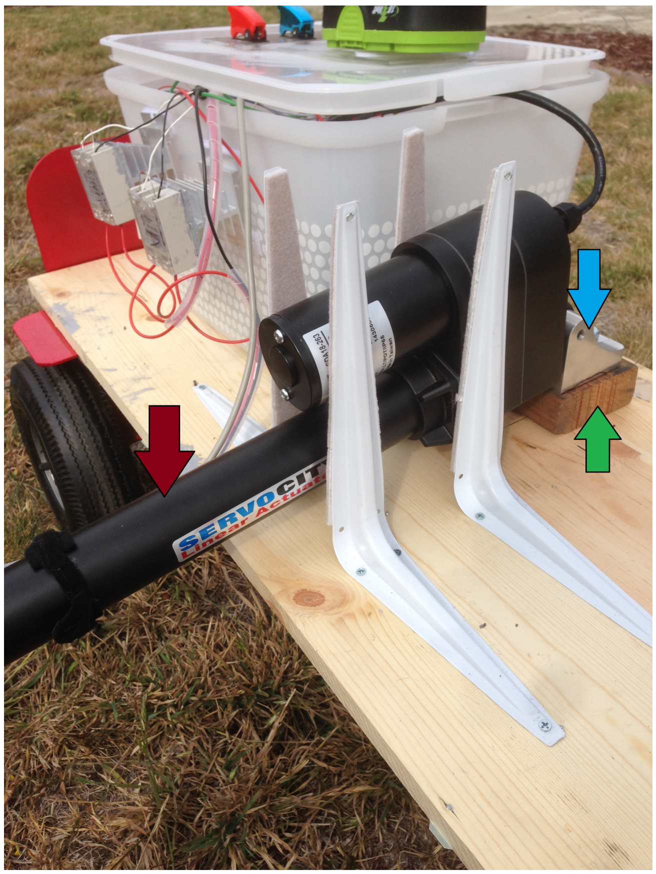


Figure 3.1: Front view of the AIRWT system on a slope with arrows emphasizing the retraction mechanism.

needed a standalone retraction system and a linear actuator was deemed to be the best component to fill this role.

3.3.2 Retracting Arm Mount

The team initially designed a pair of custom retracting arm mounts. However, after consulting with an experienced machinist, it was determined that it would take approximately six hours to fabricate the mount. Therefore, to limit time spent in custom fabrication, and to ensure a perfect fit with the linear actuator, the team elected to purchase the retracting arm mount (which is offered as a complementary unit to the linear actuator).

3.3.3 Elevated Base Mount

When virtually designing the components in SolidWorks CAD, the team observed interference between the linear actuator and the mounting vehicle deck at certain nonuniform slopes, meaning that the weed removal attachment subsystem and mounting vehicle subsystems are traversing different grades. To promote better mobility, the team chose to elevate the retracting arm mount by 1.5 inches, allowing more degrees of rotation around the retracting arm mount.

3.4 Design Methodology and Prototyping Results

3.4.1 Linear Actuator

As the customer spaces his vines between four and five feet apart on each side, it was imperative for the team to choose a linear actuator that was capable of fully reaching into the row on extension. Noting that the diameter of the cutting area was 12 inches, a linear actuator with an extension reach of 18 inches would suffice for this application. The 18 inch retraction would allow for the cutting diameter to completely avoid the vine if it were already 6 inches into the row. Figures 3.2 and 3.3 show how the 18 inch stroke allows the AIRWT to avoid an incoming trunk.

All of the linear actuators that the team considered we capable of overcoming a 1,010 pound back force; it was determined that such a force was unlikely to be encountered in the vineyard

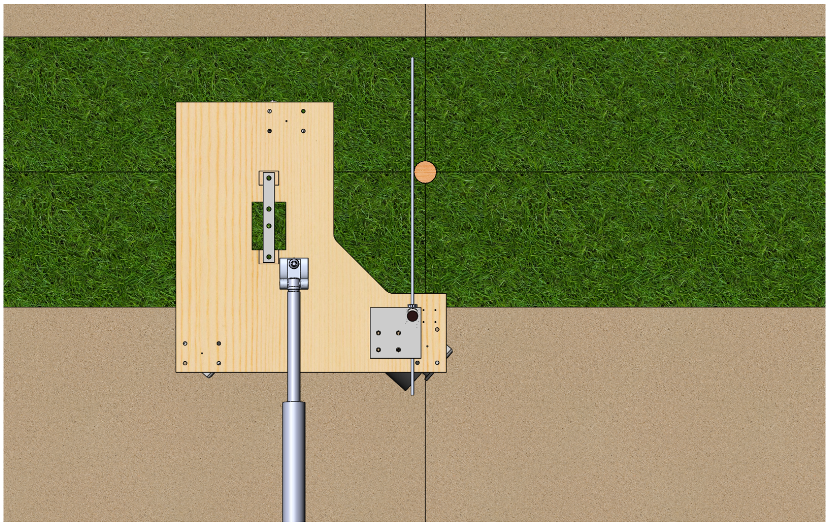


Figure 3.2: Theoretical position of the cutting head in the row while the linear actuator is fully extended.

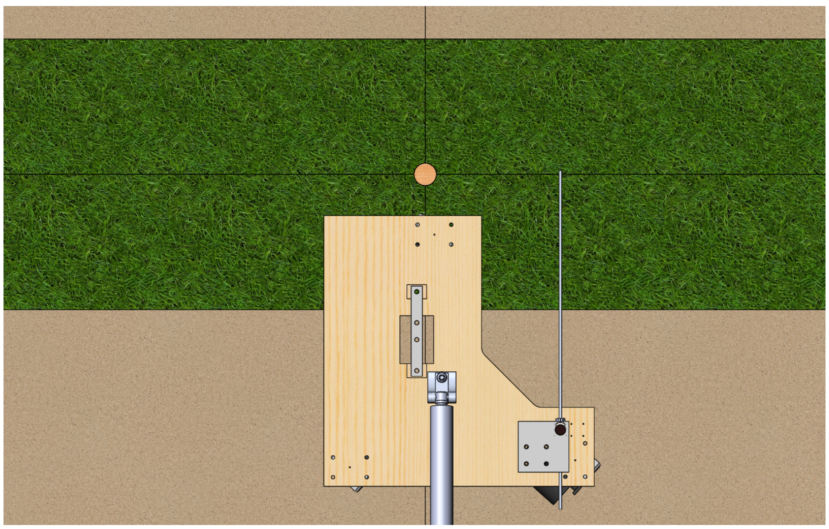


Figure 3.3: Retracted position of the cutting showing how the 18 inch stroke is capable of going around a trunk.

weeding process.

3.4.2 Retracting Arm Mount

The pivot brackets for the linear actuator were bought from the same manufacturer that provided the linear actuator, and so no designing or testing of the mounts were necessary.

3.4.3 Elevated Base Mount

To remove the interference between the linear actuator and the mounting vehicle deck, the team determined that a 1.65 inch elevation of the retracting arm mount was needed.

To easily manufacture and assemble the elevated base mount, the team elected to use wood acquired from a hardware store. The wood was then sawed to size so that it would cover the base of the retracting arm mount, and drilled so that a bolt could interface and fasten the elevated base mount, retracting arm mount, and mounting vehicle deck together.

Chapter 4

Weed Removal Attachment

4.1 Subsystem Overview

The weed removal attachment subsystem is the ”business end” of the AIRWT system. This is where the core of the weed removal system occurs.

4.2 Subsystem Components

The weed removal attachment subsystem consists of the following components:

1. Weed Removal Implement (Figure 4.1)
2. Weed Whacker Head Drop Mount (Figure 4.2)
3. Mounting Plate (Figure 4.3)
4. Support Wheels (Figure 4.4)
5. Retracting Arm Mount.

4.2.1 Weed Removal Implement

For this application, the weed removal implement is an off the shelf weed whacker adapted for the AIRWT system. In conjunction with the weed whacker head drop mount, it is fixed to the mounting plate.

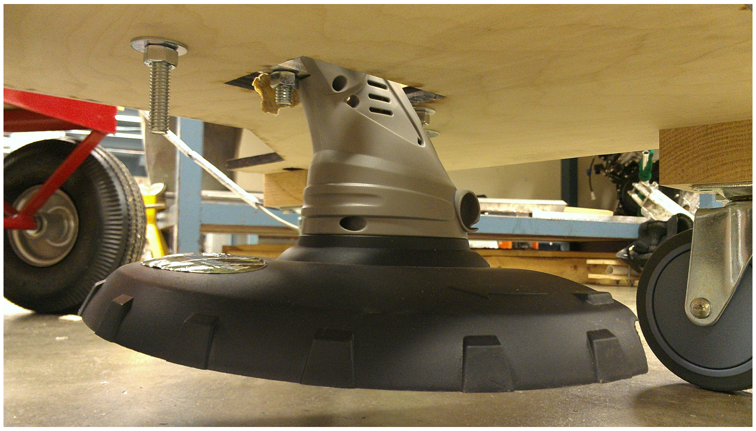


Figure 4.1: Underside view of the weed removal implemented as it is mounted onto the mounting plate.

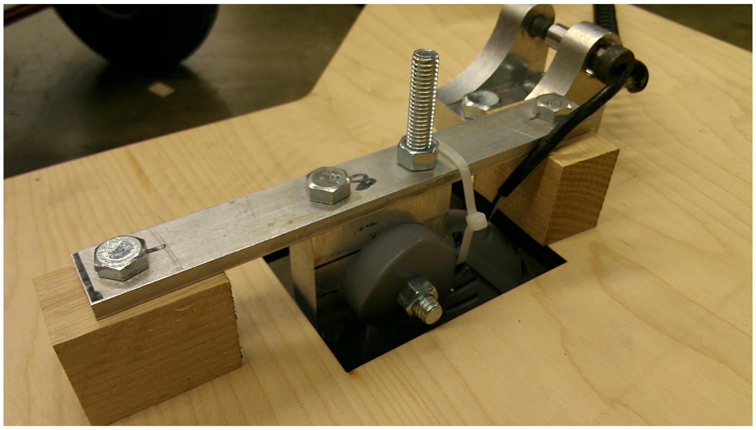


Figure 4.2: Weed removal implemented fixed to the mounting plate by means of the head drop mount.

4.2.2 Weed Whacker Head Drop Mount

The weed whacker head drop mount interfaces with the weed whacker head and the mounting plate to provide stable points of contact so that all three components may securely move as one.

4.2.3 Mounting Plate

The mounting plate provides a base on which the major cutting components as well as sensor elements are attached to.

Figure 4.3: Mounting plate with the weed removal attachment components visibly mounted..

Figure 4.4: Support wheel with the elevation block that raised its overall height.

4.2.4 Support Wheels

The support wheels (caster wheels) provide extra mobility for the weed removal attachment subsystem as it travels in and out of the rows.

4.2.5 Retracting Arm Mount

The retracting arm mount interfaces with the retracting arm (linear actuator) and provides a degree of freedom for the system, at it is a pivot point. It is the same mount shown in the Retraction Mechanism section.

4.3 Subsystem Options and Trade-Offs

4.3.1 Weed removal implement

Based on the customer requirement to remove weeds via trimming, the team did not explore methods of cultivation of tilling. In the interest of time, rather than custom developing a trimming system by pairing motors, batteries, and supporting electrical components, the team elected to purchase an off the shelf weed-whacker and adapt it for use on this particular application.

4.3.2 Weed Whacker Head Drop Mount

During disassembly of the electric weed whacker, the team discovered several potential methods of utilizing the existing components to attach to the linear actuator. However, upon further investigation, it was found that the connection points would not be secure and would be prone to displacement via vibration. As a result, a custom mount was designed and developed to interface with the weed whacker head. To reduce system complexity and time for custom fabrication, the team elected to use a simple two-piece design made from readily available 6066-T6 aluminum.

4.3.3 Mounting Plate

The design of the mounting plate required the component to support the linear actuator arm, weed whacker head, and sensor arm assembly as well as mount the support wheels. In order to house all of these components and maintain a 12 inch clearance for the cutting diameter, the size of the plate had to be 2x2 feet.

4.3.4 Support Wheels

In order the to achieve the desired height clearance for the weed whacker, the support wheels needed to have a sufficiently large diameter. This was to ensure the bottom of the cutting head would not run into the ground as the AIRWT was being pushed. Also, the wheels needed to be caster wheels to allow for retraction/extension movement while the system was simultaneously pushed forward. With the requirement for caster wheels to swivel, there was a limitation on the wheel diameter to limit the swivel diameter of the wheels. This was so the wheels would not make contact with the cutting diameter at any point during their swivel motion.

4.3.5 Retracting Arm Mount

The team initially designed a pair of custom retracting arm mounts, but after consulting with an experienced machinist, it was determined that it would take approximately six hours to fabricate the mount. Therefore, to limit time spent in custom fabrication, and to ensure a perfect fit with the linear actuator, the team elected to purchase the retracting arm mount (which is offered as a complementary unit to the linear actuator).

4.4 Design Methodology and Prototyping Results

4.4.1 Weed Removal Implement

While disassembling the weed whacker, the team discovered that the head, wires, and battery could be extracted as one unit, and that the head was actually a two-piece design mated together with screws. Disassembly of the head allowed removal of the original integrated pivot point (connected to the wiring shaft), which made it possible for the team to create a ”slot” in which a block could rest; when secured properly, the block would prevent any translation and rotational movement.

4.4.2 Weed Whacker Head Drop Mount

Using the measurements taken from the weed whacker head, the team designed a two-piece drop mount consisting of

1. Flat mount
2. Head block mount

The flat mount would interface directly with the mounting plate and the head block mount, while the head block mount would interface directly with the flat mount and weed whacker head.

For the flat mount, the team was advised to use a 3/8" thick piece of 6066-T6 barstock. To ensure secure mounting points on the mounting plate, the flat mount was designed to span eight inches in length and span one inch in width.

When designing the block mount, the team measured the height of the weed whacker head to determine how to size the height of the block while maintaining a two inch ground clearance on the head. In addition, the team mounted the width of the slot on the head as well as marked a center point through which a clearance hole could be drilled through the acrylic pin, block mount, and head for a fastener. The result was a 2" x 0.75" x 2.25" component machined from 6066-T6 barstock.

The most efficient and cost-effective method of fastening the two-piece mount together was the use of nuts and bolts. Examining the clearance between the head and mount, the team determined that the use of a 3/8" bolt would be most beneficial. To standardize all components, the team elected to use 3/8" bolts at all mounting points of this subsubsystem.

Four holes were drilled into the flat mount - two at the edges and two on either sides of the center. The holes at the edges would interface with the mounting plate, while the two at the center would be concentric with the clearance holes drilled into the block mount. An additional hole was drilled through the face block mount to facilitate fastening of the block mount to the head. All fasteners on the mount were secured into place, and the entire unit was secured to the mounting plate.

4.4.3 Mounting Plate

Due to the numerous holes required to be cut into the mounting plate—holes for the wheels, cutting head clearance, sensor arm swivel, stopping block, etc—wood was elected to be the mounting plate material. This allowed for easy fabrication by laser cutter to cut out all of the holes quickly and precisely. Birch plywood was purchased in the required 2x2 feet stock. Birch was recommended by the machine shop manager, Don MacCubbin, for its clean laser cutting characteristics and availability at local wood supplier, Southern Lumber.

4.4.4 Support Wheels

Due to required height levels, 5 inch diameter caster wheels were purchased and implemented in the design. With the addition of 1.65 inch elevation blocks between the support wheels and mounting plate and between the cutting head plate and the mounting plate, the desired 2 inch head to ground clearance was achieved. Larger wheels (+5 inches in diameter) were not compatible because larger wheel diameters would lead to larger swivel diameters that would interfere with the 12 inch diameter of the cutting line.

4.4.5 Retracting Arm Mount

The same pivot bracket used to mount the linear actuator to the mounting vehicle was used to mount it to the mounting plate. The bracket was purchased from ServoCity, the same company that provided the linear actuator. The bracket was mounted at the geometric center of the triangle formed between the three cutting wheels. To accomplish this on Solidworks, the four bolt holes of each wheel were connected by center lines to make a center point at the intersections. There were three center points in all, one for each wheel. Next, each center point was connected to form a triangle by centerlines. To obtain the geometric center of the triangle, each corner of the triangle was connected to the midpoint of opposite legs. The intersection of these three centerlines resulted in the geometric center of the triangle.

Chapter 5

Mounting Vehicle

5.1 Subsystem Overview

The mounting vehicle subsystem is the physically largest subsystem of the AIRWT. It facilitates system movement through the rows and provides a mounting point for the electronics housing subsystem as well as a mounting point for the retracting mechanism subsystem.

5.2 Subsystem Components

The mounting vehicle subsystem consist of the following components:

1. Push Cart (Figure 5.1)
2. Base Deck (Figure 5.2)
3. Fasteners (Figure 5.3)
4. Linear Actuator Guides (Figure 5.4)

5.3 Subsystem Options and Trade-Offs

5.3.1 Push Cart

While the team initially wished to pursue development of a fully robotic/autonomous mounting vehicle, the time and budget constraints prevented the team from taking this route. As the

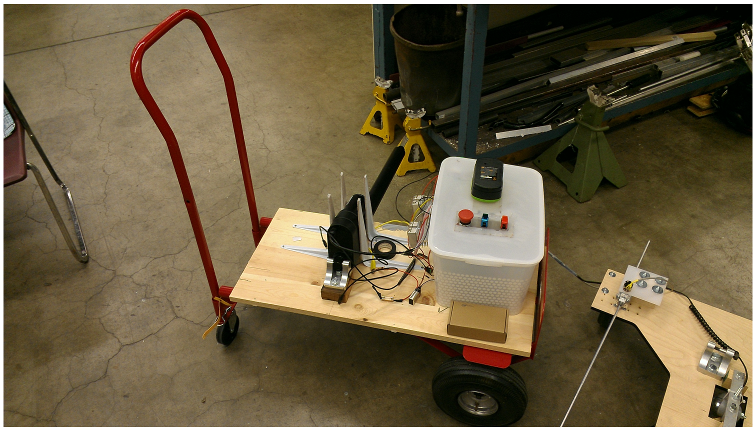


Figure 5.1: Push cart purchased to function in place of the autonomous vehicle.

team searched for viable alternatives, it became apparent that the system would revert to a semi-autonomous state, requiring a human operator to push/drive the entire system. With this realization in mind, the following options became apparent:

1. Develop a custom mounting vehicle from scratch with sheet metal, axles, wheels, etc.
2. Purchase a base mounting vehicle and perform minor modifications to adapt to this particular application.

In the interest of time and cost, the team decided to purchase a mounting vehicle—a metal dolly cart—to adapt for vineyard use.

5.3.2 Base Deck

As the dolly was of a tubular design, there was no viable method of attaching the retracting mechanism subsystem and electrical subsystems to the mounting vehicle. Therefore, the team elected to use a wooden board as a base deck of the mounting vehicle on which other subsystems could be mounted.

5.3.3 Fasteners

Securing the base deck to the push cart required the use of fasteners, which in this application were hose clamps and screws. This ensured a secure interface between the push cart and the base

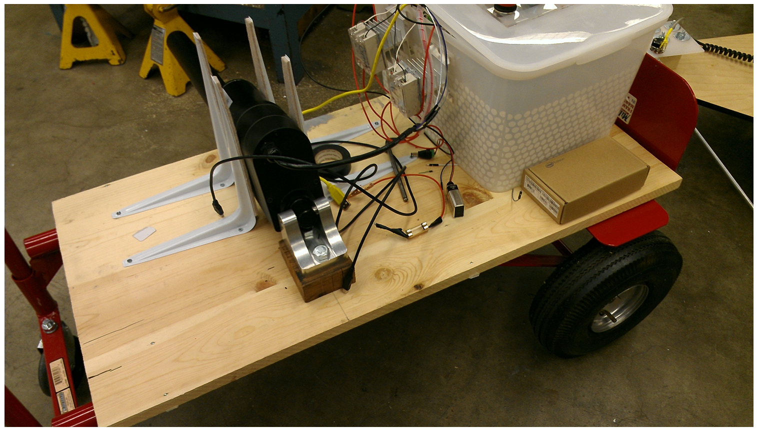


Figure 5.2: Wood board that served as the base deck on the push cart.

Figure 5.3: Fasteners that mounted the base deck to the push cart.

deck, preventing any unwanted translation/rotational movements due to vibrations.

5.3.4 Linear Actuator Guides

While designing the retracting mechanism subsystem, the team realized that if a moment were to be exerted on the leading edge of the weed removal attachment subsystem when the linear actuator is at full extension, the entire retraction mechanism subsystem would rotate and possibly introduce inaccuracies with sensor readings. To eliminate the possibility of the entire retraction mechanism rotating, the team elected to use shelf supports as guides, preventing the linear actuator from rotating in either direction.

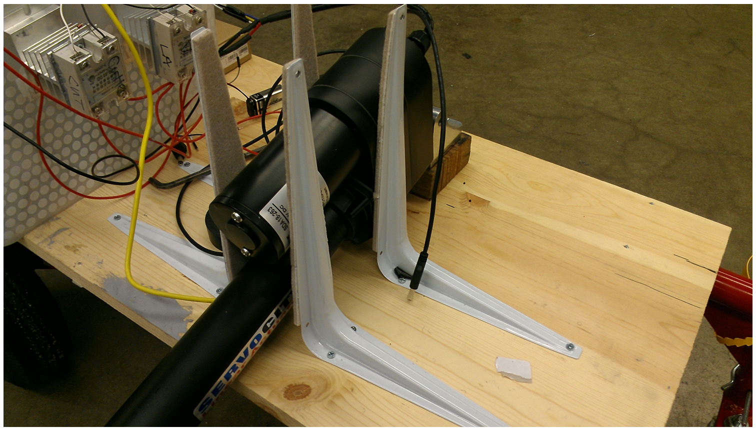


Figure 5.4: Shelf supports that acted as guides for the linear actuator.

5.4 Design Methodology and Prototyping Results

Noting the diameter of the push cart structure tubes, the appropriate fasteners and screws were paired together. The team then cut the deck to size so that it covered the top surface of the dolly with a half inch overhang on three sides (the fourth size rested against the push cart handles). Once the team positioned the deck, four clamps were placed around the push cart tubes, along the edges of the deck. The overhang on the deck allowed the team to drill screws through the clamps and into the wood, thus tightening the clamps around the tubes and securing the deck and push cart together.

Once the deck and push cart assembly was completed, the retraction mechanism subsystem and electronic subsystem components were laid out on the deck. Markings were made to indicated the positions at which each components would rest on the deck. The team was then able to determine the position for the linear actuator guides, and the guides were secured into place using wood screws drilled through the shelf supports and into the deck.

Chapter 6

Sensor Arm Assembly

6.1 Subsystem Overview

The sensor arm assembly is the most critical subassembly of the full system as it provides the system with the information needed to know whether to retract or extend the linear actuator. Without this key feature, the system would not be autonomous.

6.2 Subsystem Components

The sensor arm subsystem consists of the following components:

1. Sensor Arm (Black)
2. 1/4” Clamping Hubs (Red)
3. U-Channel (Teal)
4. Swivel Hub (Blue)
5. Flat Single Bracket (Gray)
6. Spring (Yellow)
7. Stopping Block (Wood Finish)
8. Potentiometer (Black, Silver, Brown)

9. Potentiometer Fixed Plate (Off White)
10. Potentiometer Clamping Hub (Orange)
11. Potentiometer Hub Mount (Purple)

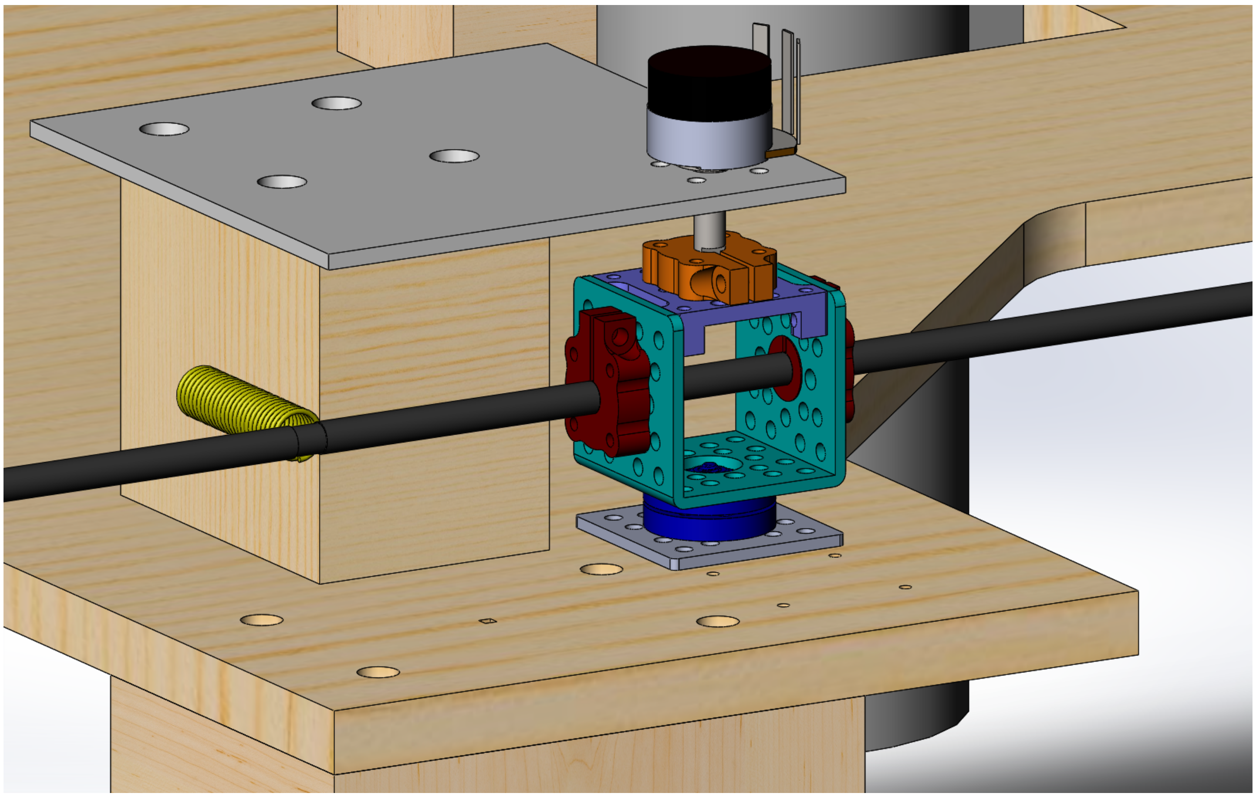


Figure 6.1: CAD model of sensor arm assembly.

6.3 Subsystem Options and Trade-Offs

Since the early stages of the design process, the sensor arm design had consisted of an aluminum rod acting as the sensor arm. The only feature that needed to be designed was the mechanism that would relay angular displacement information to the microprocessor. The original design implemented a wheel on the short end of the sensor arm to impart a force along a curved force sensor strip.

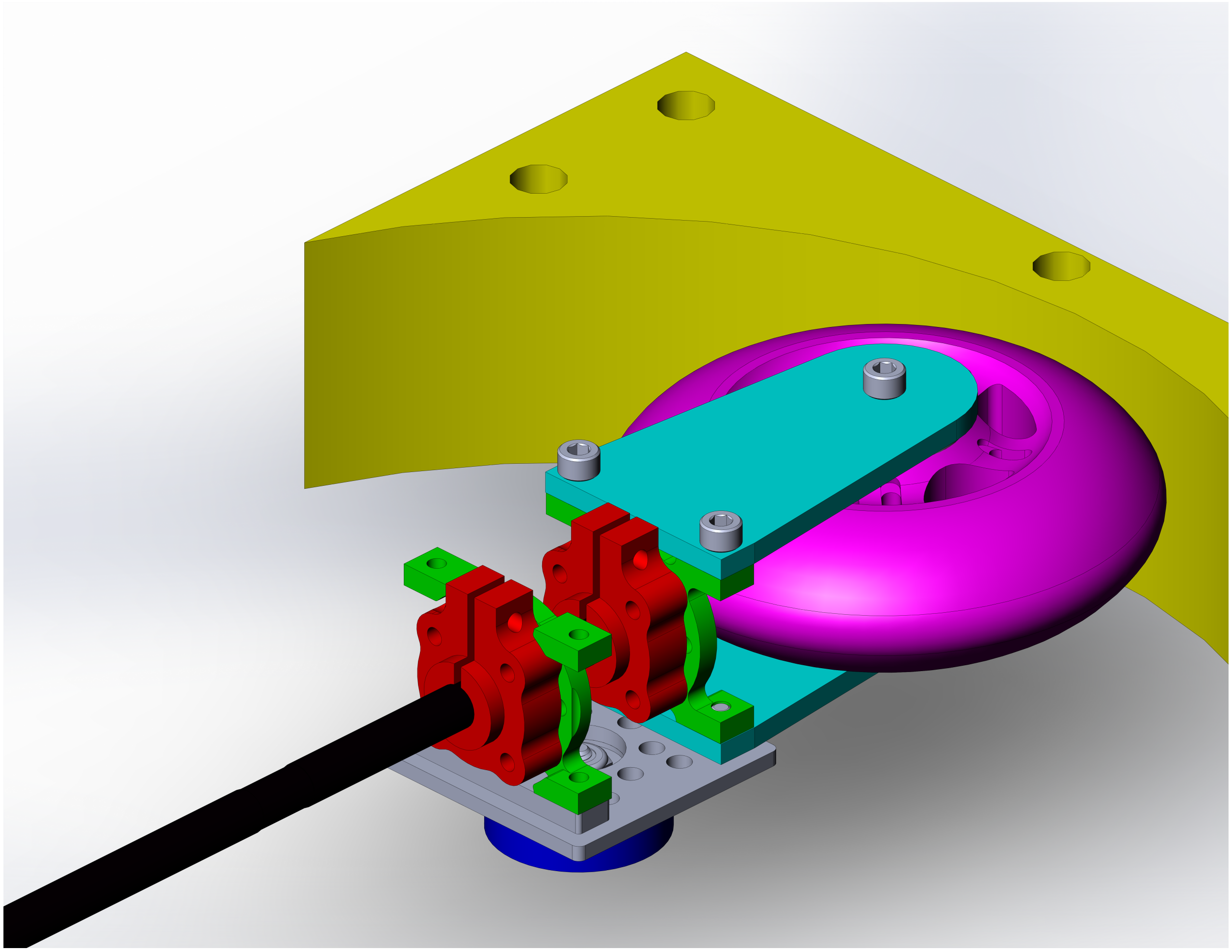


Figure 6.2: Retired CAD model of sensor arm assembly.

It was quickly realized that the design shown in Figure 6.2 was over complicated for what we were trying to accomplish. After taking a suggestion from Dr. Timothy Hight, the potentiometer design shown in Figure 6.1 was modeled and built.

Referring back to Figure 6.1, the sensor arm is mounted to the plate and allowed to swivel due to the swivel hub, U-channel, and 1/4" clamping hubs. The angular deflection is transferred to the potentiometer by the potentiometer clamping hub and hub mount. The potentiometer fix keeps the top half of the potentiometer at a fixed position and attitude ensure that the angular deflection translates entirely to the potentiometer's knob. The spring acts as a restoring force to bring the sensor arm back to a neutral position that is set by the stopping block.

6.4 Design Methodology and Prototyping Results

The clamping hubs, hub mount, U-channel, swivel hub, and flat single bracket were all purchased online at Servocity.com, thus reducing the amount of custom fabrication. The sensor arm was an aluminum rod that was purchased in the correct size at a local hardware store along the spring. The potentiometer was also purchased off the shelf, leaving the potentiometer fix as the only part that was custom fabricated. The potentiometer fix was fabricated out of a single sheet of 1/8” acrylic through laser cutting.

Chapter 7

Microcontroller and Supporting Electronics and Software

7.1 Subsystem Overview

The goal for the electronics and software of the AIRWT system was to move the cutting head to a desired position based on the vine. The cutting head was moved by retraction and extension of the linear actuator. The vine was detected by the deflection of the sensor arm. The electronic circuit comprised of a linear actuator, cutting head, motor driver and potentiometer on the sensor arm. The Intel Edison with Arduino breakout board were used as the microprocessor driving the circuit.

7.2 Electronics

The circuit is comprised of components that run at different voltage levels. Relays were implemented to activate the cutting head and linear actuator using the Arduino microprocessor. Referring to Figure D.1 in Appendix D, the area shaded in yellow denoted the regions of the circuit powered at 5 volts, the green region used 18 volts to power the cutting head, and the red region ran at 12 volts, powering the linear actuator.

Diodes were placed in parallel with the relays to handle the energy when the relay was switched off. The fuse, placed after the double throw double pull (DTDP) emergency switch (E-stop) was used to prevent voltage spikes from entering the H-Bridge. The circuit had three physical switches, two that turned off the relays on the low voltage side, and the DPDT emergency switch on the high voltage side. All of the grounds were connected to a common, neutral aluminum bar. This was done to avoid a circuit with a floating ground.

The system consisted of the following electrical components:

7.2.1 Linear Actuator

The linear actuator was selected based on its power capabilities. Initially, when designing the system, we assumed that tilling was the desired mode of weed removal. Therefore, we assumed that the mechanism used to move the cutting or tilling tool would need to have high power or thrust capabilities. For this reason, we selected the Super Duty SDA18 18 Stroke linear actuator from ServoCity. The 18" stroke length was selected based on the 5ft by 5ft dimensions of the rows, specified by our customer. The Super Duty linear actuator had 560 lbs. thrust capabilities with a maximum speed of 2.63 inches per second. The linear actuator was driven forward and reverse, translating to extension and retraction, by applying a positive or negative 12 volts across its leads, like a DC motor. Monitoring of the position of the linear actuator along its slide was made possible through the potentiometer built into the linear actuator. The specifications sheet appears in the Electrical Components Appendix, specifically Figures E.1 and E.2.

7.2.2 Cutting Head

The team used the motor and battery assembly of a standard electric cordless weed trimmer: Earthwise Cordless 18 Volt String Trimmer, CST00012 model. The electric weed trimmer was selected to keep the cutting process simple. Purchasing a simple, pre-existing system meant that we just made small alterations to add the cutting mechanism to the AIRWT system. The hold-down switch of the trimmer was removed and replaced with the DPDT switch when added to the AIRWT circuit. The part specification sheet is in the Electrical Components appendix, specifically Figures E.3 and E.4.

7.2.3 Microprocessor

The Intel Edison is an affordable module with a low-power, high speed processor, WiFi, and Bluetooth Radios on board. The AIRWT system used the Intel Edison Development Platform that included an Arduino Breakout board, see Figures E.5 and E.6, which essentially gave the Edison the ability to interface with analog and digital I/O pins, a DC power supply jack, and much more. This in turn enabled the control of the AIRWT to be written in Arduino Sketch. This microprocessor allowed us to use it as a simple Arduino, but the system can easily be built up. The Intel Edison was selected because of the project's potential to be worked into a more complex system.

7.2.4 Motor Controller

To control the linear actuator, a motor driver was selected. By pulsing the voltage, the motor controller achieved forward or reverse motion, retracting or extending the linear actuator. The linear actuator runs at 12 volts and 20 amps. Based on these specifications our motor controller was selected. The Pololu Simple High-Power Motor Controller 18v25 controller handles between 5.5-30 volts and 25 amps, for more specifications see Figures E.7- E.11 in the Appendix. The motor controller was plugged in directly to the linear actuator, and in its current iteration was powered by a 12 volt lead acid battery. The motor controller was a critical component because it allowed the linear actuator to be easily controlled like a standard servo motor.

7.2.5 Sensor Arm Potentiometer

A potentiometer was used to detect the deflection of the sensor arm. The microprocessor was used to power and detect the resistance through the potentiometer. The Philmore PC245 24mm potentiometer was selected because of its 10K ohms linear taper resistance, see Figure E.12. The potentiometer has a resistance ranging between 500 to 1M ohm. This resulted in analog values read by the microprocessor between 50 at its neutral position and 250 at maximum deflection.

7.2.6 Other Components

To protect the circuit from a large surge when the switches are shut off, diodes were added to the circuit. The diodes used in this circuit were rated at 12 volts and 1 Watt, for more specifications see Appendix Figures E.13-E.15. The relays had a low voltage side of 3 to 32 volts and linked to a high voltage flow of between 5 and 10 volts.

7.3 Software

A flowchart was generated to visualize the logic that would go into the AIRWT cutting process, see Figure F.1. The top section of the flowchart is the initial set-up safety checks. The gray region indicates the portion of the code that operates in a loop, controlling movement and cutting. Within the operating loop, the linear actuator is changed based on the deflection of the sensor arm and the current position of the linear actuator along its slide. The Arduino script is presented in Appendix F.2.

7.4 Subsystem Trade-Offs and Optimization

Initially, the sensor arm was designed with a force sensing strip and operated on a pivot with a wheel attached the opposite end. When the wheel moved along the strip, the degree of the deflection of the sensor arm would be detected. However, upon testing the force sensing strip, it was not as sensitive as we desired, and the strip presented false and sporadic data when it was tested with the Arduino. Thus, we traded the force sensing strip to a potentiometer that was mounted directly to the pivot, which made the system more robust both physically and electrically.

Chapter 8

Electronics Housing

8.1 System Overview

The primary purpose of the electronics housing was to protect the sensitive electronic components from both the elements as well as impacts, the most notable components being the microprocessor and the digital speed controller. The housing also served a secondary purpose of organizing loose wires coming from the components. Lastly, this system served to protect the users from electrocution.

8.2 Subsystem Components

The housing consisted of the following sub-components:

1. Main Housing (Figure 8.1)

2. Switch Mounting Plate (Figure 8.2)

8.2.1 Main Housing

The main wire housing for the AIRWT consisted of a plastic storage container, which was chosen for its dimensions of 11.5x15x9 inches (i.e., large enough to fit all components), rigidity, toughness, and machinability.

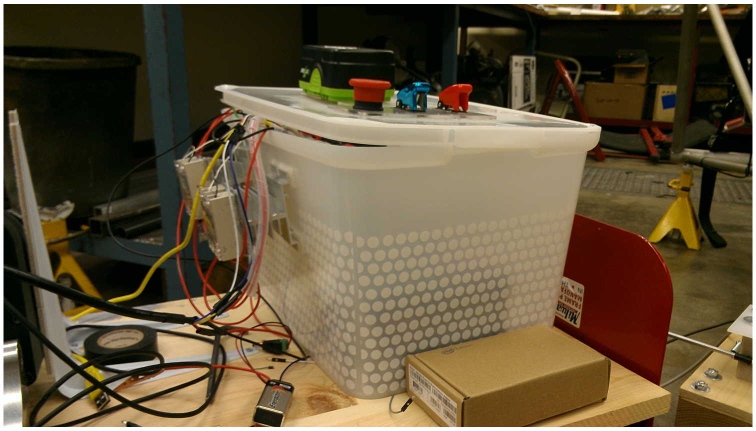


Figure 8.1: HDPE tub housing all of the electronic equipment.

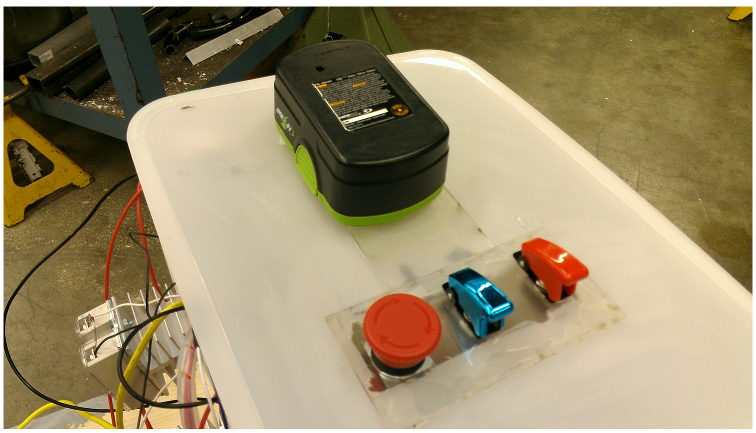


Figure 8.2: Switch mounting plate containing the two toggle switches and emergency kill-switch. Also shown is the cutting head battery.

8.2.2 Switch Mounting Plate

A mounting plate was created in order to connect the two toggle switches and the emergency kill-switch (E-stop) to the housing. This plate was made from laser-cut acrylic to allow for precise and custom fittings. Having the plate separate from the housing lid also further reinforced an area that was predicted to experience high stress from use.

Chapter 9

Cost Analysis

The total amount spent by the AIRWT team for the academic year of 2014-2015 was approximately $1,800 of the $2,500 approved and provided by the Santa Clara University School of Engineering.

The funds were used to purchase parts and raw materials needed to complete the AIRWT prototype. The largest allocation of this budget was $400 for the linear actuator. The Intel Edison microprocessing unit and Arduino break-out board were provided by the University, and even though it incurred no cost to the team, its price was included in the project's estimated cost to manufacture $1,316.61. Additionally, under the assumption of a ten percent discount for purchasing parts in bulk, the cost to manufacture the AIRWT system is estimated to be $1,184.95.

Compared to the streamlined manufacturing cost, prototyping the AIRWT system cost approximately $1,800, spent throughout the nine-month design cycle. This extra cost was incurred primarily through multiple changes to the motor controller model.

A detailed breakdown of the bill of materials for the manufacturing of one AIRWT system can be found in Appendix K.

Chapter 10

System Integration, Testing, and Results

10.1 Experimental Protocol

10.1.1 Overall Objective

Broadly, the performance objectives of the AIRWT system are that it should be able to:

1. Accommodate Hillsides

2. Successfully Operate for a Variety of Mounting Vehicle Velocities

3. Cut Precisely

The overall objective of the experimental protocol is to safely and reliably quantify the success of the AIRWT's ability to perform these tasks. All other specifications (such as weight, reach, retraction speed, etc.) could be satisfied through the mechanism design and did not require in-depth experimental protocol and analysis. The specific, numeric performance objectives can be found in the Product Design Specifications detailed in Appendix H.

10.1.2 Safety Protocol

Dealing with voltages as high as 18 V, current as high as 3 A, and components that could output over 500 lb thrust, it was critical to approach the experiments safely. Additionally, a major subsystem of the AIRWT comprises of a cutting implement. Proper care must be taken to prevent the risk of personal injury during operation. As a precaution, the AIRWT team has elected to include on-board kill switches in the event the AIRWT system experiences a failure. In addition, the cutting head will be enclosed in order to shield the cutting implement as well as prevent the rapid ejection of possibly harmful debris and/or projectiles.

For persons working near the system, standard landscaping attire and protection is required. This includes but is not limited to: closed-toed shoes (boots recommended), hearing protection, eye protection, long pants, etc.

During operation, the team recommends that system supervisors stand behind the cutting head during manual operation of the mounting vehicle, and stand at least ten feet away during automated operation of the system. Bystanders are recommended to stand at least ten feet away, allowing enough time and distance to react in the case of a catastrophic system failure.

10.1.3 Evaluation

Below are the criteria which were evaluated:

1. Operation Angle
2. Cut Precision
3. Mounting Vehicle Speed Performance
4. Weight
5. Arm Reach
6. Kill-Switch Performance
7. Extension and Retraction Speed

Due to time constraints and unforeseen electrical and mechanical issues, grass cutting and sloped testing were not achieved during the duration of this project. Flat surface testing was conducted with procedures that simulated the cutting head cutting grass. These procedures are covered in more detail in the following sections.

10.1.4 Experimental Tasks and Testing

Operation Angle

For safety purposes, all power sources on the AIRWT system will be disconnected and removed, the cutting head will be removed, and all loose wires will be taped.

Datum measurements were made prior to displacing the angle. The height of mounting vehicle and the mounting plate were measured while they were on flat ground. The length of the linear actuator from pivot point to pivot point was also measured—this acts as the hypotenuse of the triangle. The operator then proceeded to raise the mounting vehicle to simulate the cutting head being at a lower elevation compared to the mounting vehicle. The mounting vehicle was lifted until the linear actuator made contact with the edge of the mounting vehicle. Height measurements were taken on the same locations on the mounting vehicle and the mounting plate. The angle of this lower elevation was obtained using simple trigonometry. This would act as the lower angle limit of the system.

This process was repeated in a modified format to simulate the cutting head being at a higher elevation. Instead of lifting the mounting vehicle, the mounting plate was lifted until the linear actuator was about to leave contact with the shelf supports that acted as linear actuator guides. If the linear actuator were to break contact with these guides, the moments acting on the linear actuator would be too great for the system to properly function. Similar height measurements were taken at the same location on the mounting vehicle and the mounting plate while the cutting head was raised. Trigonometry was again used to determine the angle. This would act as the upper angle limit of the system.

Mounting Vehicle Speed Performance

Before testing, proper safety attire and setup were ensured. All engineers present were wearing pants, closed-toed shoes and safety glasses. All persons present were not directly conducting the test (i.e., video recorders, observers, etc.) maintained a safe distance.

To determine the speed at which the tester was walking, an online metronome was played at frequencies of 30 and 60 beats per minute (bpm). The tester would take a toe-to-heel step at each beat. Because each step was 1 foot long, a 30 bpm tone resulted in a 0.5 ft/s speed and a 60 bpm tone resulted in a 1 ft/s speed. Practice runs were conducted without pushing the cart to achieve a feel of walking smoothly at these speeds.

With the test engineer familiar with these speeds, the test engineer pushed the AIRWT system into four circular posts of varying diameters that simulated vine stalks and other obstructions. The cutting mechanism was lined up to each post so that the edge of the cutting diameter was in line with the posts. A speed failed the test if any part of the mounting plate made contact with the post.

Cut Precision

This test followed the same safety procedures as the Speed Performance test previously described.

With the cutting mechanism turned off but the linear actuator system powered, the theoretical cut precision around a simulated vine stalk was measured. Walking at about optimal speed determined in the Speed Performance test, the AIRWT system was pushed so that the sensor arm would be displaced by an aluminum rod that acted in place of a vine. The entire time, a video recording was taken of the cutting mechanism interacting with the rod from a top view looking down. Prior to testing, a yard stick was taped onto the top of the mounting plate in view of the camera so that the stick was parallel with the neutral sensor arm position without any possibility of the stick hitting the rod. The yard stick was implemented to determine the distance between the rod and the cutting diameter and check if the mechanism can indeed cut in between the rows. This distance was along the linear actuator axis and measured before the linear actuator began to retract. Several iterations were conducted with varying distances to determine the optimal intra-row depth for vine avoidance and cutting thoroughness.

Weight

The digital scale was zeroed at a fixed location. The carrier weighed himself to establish the weight offset when carrying the components. One at a time, the carrier weighed himself while carrying the linear actuator, cutting head mechanism, and electronic housing. The weight of each component was determined by simply subtracting the weight of the carrier from the weight displayed while carrying each component. The weight of each component was added together to determine the weight of the AIRWT system. This process was repeated by another carrier to obtain an average value.

The weight of the push cart and base deck were not measured because these components would ideally be replaced in the fully automated system.

Arm Reach

The trimmer head subsystem was switched off for the duration of this test. The area around the AIRWT system was cleared to ensure nothing would obstruct the cutting mechanism while the linear actuator was fully extended. The linear actuator was then turned on and allowed to fully retract before being stopped. With the linear actuator subsystem turned off, the distance from the edge of base deck on the side of the linear actuator mount to the farthest edge of the mounting plate. If the AIRWT system were tightly enclosed in a box, this measurement would be of the box's width. This procedure was repeated with the linear actuator fully extended.

The minimum distance from the edge of the cutting diameter to the same edge of the mounting plate was also measured. This distance was subtracted from the retracted and extended measurements previously obtained. Whereas the previous set of measurements gave the minimum row widths the system could fit in, these measurements relative to the cutting head can be used to determine how far the cart needs to be from the line of vine stalks to achieve a certain cut path.

Kill-switch Performance

This test was a simply pass/fail to determine the functionality of the AIRWT electrical system. The system turned on by simply releasing the E-stop and flipping the switches (cutting head and linear actuator). The cutting head was tested by simply flipping the red switch the other way to see if the cutting head would stop.

Similarly for the linear actuator, the sensor arm was displaced to signal the linear actuator to retract. Then, the blue switch for the linear actuator was flipped to observe if the retraction stopped.

The E-stop was tested in the same manner but with both system running. The cutting head was turned on and the sensor arm was displaced to force the linear actuator to retract. Rather than flipping the individual switches, the E-stop was pressed to stop both systems.

Extension and Retraction Speed

This test was conducted using only the linear actuator and the body. Due to the weight of the cutting mechanism most likely being an order of magnitude below the maximum load (560 lb), it was assumed the free retraction and extension of the linear actuator would yield the same speed as it would when fully attached to the system.

To determine the speed, the linear actuator was laid flat with a yard stick next to the extension path of the arm. With the linear actuator already fully retracted, the linear actuator was connected to the battery to get the arm to fully extend. The movement of the arm with the yard stick acting as a reference was recorded on a smart phone. Both full extension and retraction movements were recorded. The speed was obtained by simply dividing the distance traveled (18 inches) by the time it took to cover this distance, which was determined by simply looking at the video recordings.

10.1.5 Experimental Results

Operation Angle

Table 10.1 shows the maximum and minimum angles of operation derived from the Operation Angle test. The distance measurements were recorded to the nearest quarter inch. This quarter inch tolerance yields about 0.5° in error, which is minuscule enough to be negligible. Because the criteria for the upper and lower limits were visually apparent—the linear actuator not touching the shelf supports and the linear actuator touching the cart deck, respectively—there was a high repeatability factor for this test. Even if it were not as easily repeatable, the 0.25 inch tolerance would have allowed for repeatable results.

Table 10.1: The experimental results of the Operation Angle test

Parameter	Distance (in)	Angle (degrees)
Pivot-to-Pivot Distance	33	N/A
Maximum	12.00	19.83
Minimum	-6.25	-10.72

Mounting Vehicle Speed Performance

Table 10.2 shows the results of the Mounting Vehicle Speed Performance test. Each outcome represents the AIRWT system moving past a set of 4 posts.

Table 10.2: The experimental results of the Mounting Vehicle Speed Performance test

Speed (ft/s)	Outcome
0.5	Pass
	Pass
	Pass
1.0	Fail
	Pass
	Fail
1.5	Fail
	Fail
	Fail

Cut Precision

Table 10.3 shows the results of the Cut Precision test. The ”Distance” parameter represents the initial distance the post was positioned relative to the center of the cutting head, perpendicular to the cart path.

Weight

Table 10.4 shows the weight of the AIRWT system. The weight of the mounting vehicle was not included as it is not intended for the same vehicle to be used in future iterations.

Table 10.3: The experimental results of the Cut Precision test. Cart deck moved at a speed of 0.5 ft/s.

Distance (in)	Outcome	Notes
1	Fail	Collision with mounting plate and trimmer
3	Fail	Collision with mounting plate; no collision with trimmer
4	Fail	Collision with mounting plate; no collision with trimmer
7	Pass	Trimmer barely in contact with row

Table 10.4: The results of weighing the AIRWT components.

Part	Trial 1 (lbs)	Trial 2 (lbs)
Electrical	15.5	15.6
Mechanical	33.3	33.0
Total	48.8	48.6

Arm Reach

Table 10.5 shows the results of the Arm Reach test.

Table 10.5: The results of arm reach test.

Parameter	Value (in)
Fully retracted	32.77
Fully extended	50.76

Kill-switch Performance

Table 10.6 shows the results of the Kill-switch Performance test.

10.1.6 Experimental Discussion

The electronic components work according to design. However, the linear actuator's speed became a limiting factor for the precision and operating capabilities of the AIRWT. The system was not able to take full advantage of the PID controller implemented due to the low speed. Possible improvements for this include a faster linear actuator or placing the sensor arm farther away from the linear actuator pivot. Placing the sensor arm farther away would provide more time for the

Table 10.6: The results of the kill-switch tests.

Trial No.	E-Stop	Toggle (Trim)	Toggle (Act.)
Trial 1	Pass	Pass	Pass
Trial 2	Pass	Pass	Pass
Trial 3	Pass	Pass	Pass
Trial 4	Pass	Pass	Pass
Trial 5	Pass	Pass	Pass
Trial 6	Pass	Pass	Pass
Trial 7	Pass	Pass	Pass
Trial 8	Pass	Pass	Pass

linear actuator to react to deflections on the sensor arm.

10.2 Simulations

10.2.1 Finite Element Analysis

Finite element analysis was performed on the following parts to simulate the stress and strain of operation:

- Sensor Arm
- Mounting Plate

The simulation was created using SolidWork's SimulationXpress Analysis Wizard. The Xpress feature output the stresses and deflections in metric units and had to be converted to psi and inches, respectively.

Sensor Arm

The sensor arm stress and deflection simulation was created by fixing the aluminum rod at two points—one at the location of each clamping hub. A 2 lb force was placed normal to the sensor arm at a length four-fifths the length of the sensor arm. Figure 10.1 shows the simulation's setup. The graphical results as well as the full SolidWorks Simulation reports can be found in Appendix C.

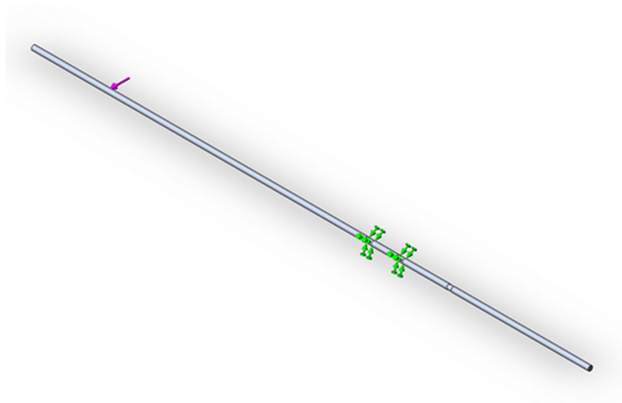


Figure 10.1: The force locations for the SolidWorks finite element analysis of the sensor arm. Fixed locations are shown in green; force locations and directions are shown in magenta.

Mounting Plate

The mounting plate stress and deflection simulation was created by fixing the plate at the mounting holes for the linear actuator stroke. The mounting plate underwent three simulated forces—one located at the centroid of each wheel-connection interface. Each force was simulated to be 50 lb as that was the expected weight of mounting plate, linear actuator, and all of the other mechanical components excluding the push cart. Figure 10.2 shows the simulation's setup. The graphical results as well as the full SolidWorks Simulation reports can be found in Appendix B.

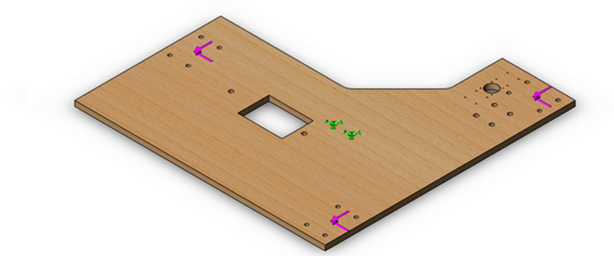


Figure 10.2: The force locations for the SolidWorks finite element analysis of the mounting plate. Fixed locations are shown in green; force locations and directions are shown in magenta.

Results

The finite element analysis showed that neither of these parts would fail. Tables 10.7 and 10.8 show the relevant simulation results. Table 10.7 shows the sensor arm would have a max deflection of 2.20 inches under the assumed conditions. While this may seem very large, a 2 inch deflection is not very significant considering the overall length of the sensor arm (30 inches). Also, the conditions tested were worst case scenarios. Because the sensor arm is allowed to swivel, the actual force would not be acting perpendicular to the face of the sensor. The only time the force would be perpendicular to the arm's length would be during initial contact, which would immediately enforce the swivel motion, thereby changing the angle between the force and the sensor arm. The mounting plate was also subjected to worst case scenario conditions with three 50 lb forces acting on it. As can be seen in Table 10.8, the mounting plate has a factor of safety of more than 2, making it usable without a chance of failure.

Table 10.7: The simulated stresses and deflections of the sensor arm.

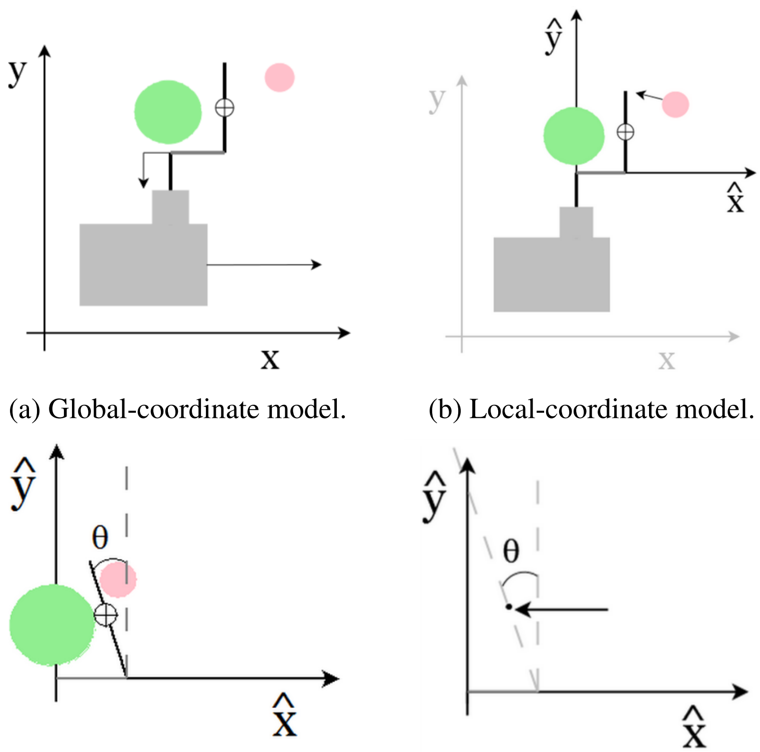
Characteristic	Value
Maximum deflection	2.20 in
Maximum stress	3.39E4 psi
Yield stress	3.99E4 psi

Table 10.8: The simulated stresses and deflections of the mounting plate

Characteristic	Value
Maximum deflection	6.46E-3 in
Maximum stress	1.04E4 psi
Yield stress	2.90E4 psi

10.2.2 Matlab Simulation

The AIRWT system was modeled by having a reference frame fixed to the leading end of the linear actuator, shown in Figure 10.3b. This was done to alleviate the emergence of non-linear equations of motion that arise with a global reference frame. The partial derivation for the equation of motion according to the coordinate system in Figure 10.3a can be found in Appendix C.3. Figures 10.3c and 10.3d show the localized model in its deflected state.



(a) Global-coordinate model.

(b) Local-coordinate model.

(c) Local model deflected.

(d) Simplest form.

Figure 10.3: The progression toward deriving the equations of motion.

Using Lagrangian mechanics, the equation of motion was found to be

$$\ddot{\theta} + \frac{k}{M(L/2)^2}\theta = \frac{k}{M(L/2)^2}\mathcal{R}(t-\tau) \tag{10.1}$$

where θ represents the angular deflection of the sensor arm, k represents the torsional spring constant of the sensor arm, M represents the total mass of the sensor arm, L represents the length of the sensor arm, and $\mathcal{R}(t-\tau)$ represents a ramp input occurring at time τ.

This model was implemented into Simulink, driven by a repeating ramp input and controlled by a PID system. The block diagram can be found in Appendix C. Figures 10.4, 10.5, 10.6, and 10.7 show the open-loop response, the closed-loop response for $K_P = 5$, the closed-loop response for $K_P = 1, K_I = 1$, and $K_D = 2.5$, and all tested responses, respectively.

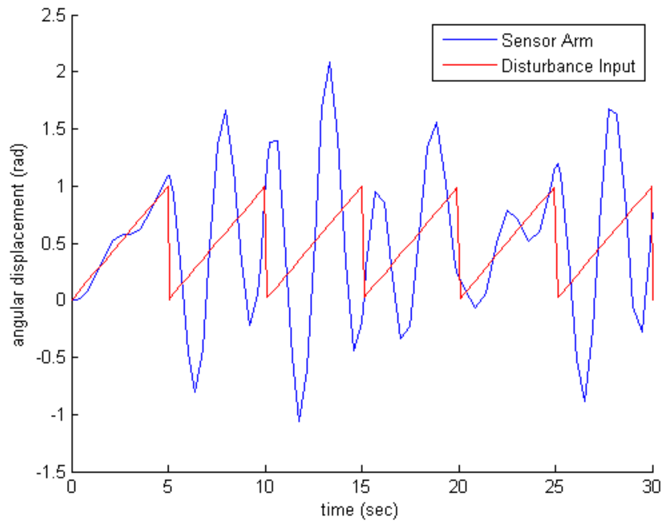


Figure 10.4: The open-loop response of the system subject to the input disturbance in red.

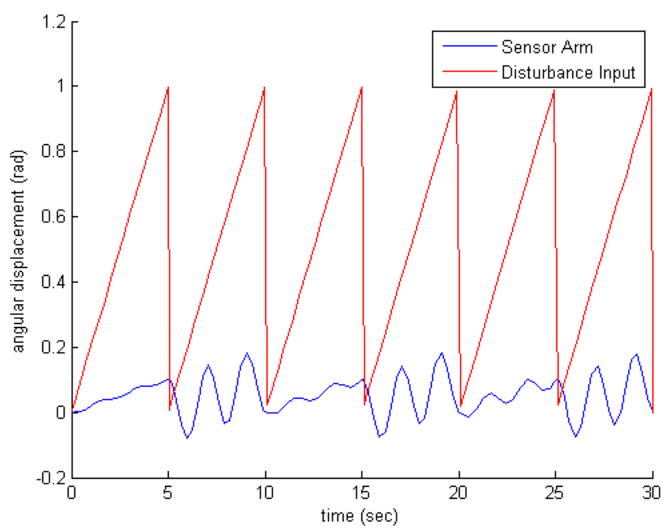


Figure 10.5: The closed-loop response of the system subject to the input disturbance in red with only a proportional gain.

Results

Figure 10.7 clearly shows the superior response of a PID controller compared to a proportional control and an open loop system. Implementing a PID control would not only improve response time compared to the other control systems, but it would also reduce the overshoot [5]. By reducing

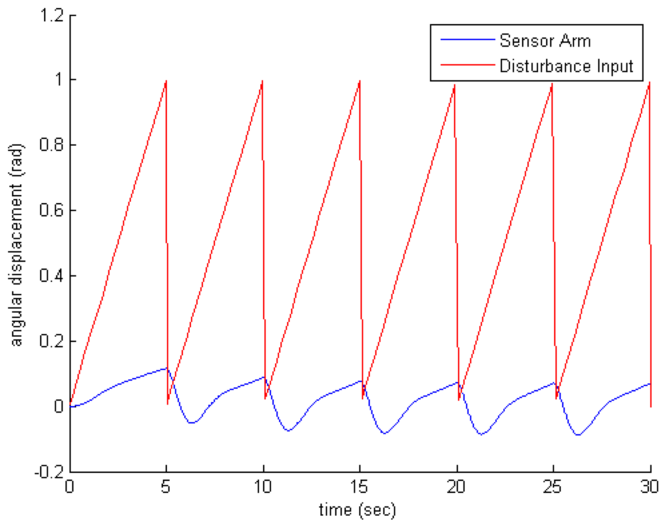


Figure 10.6: The closed-loop response of the system subject to the input disturbance in red under a full PID controller.

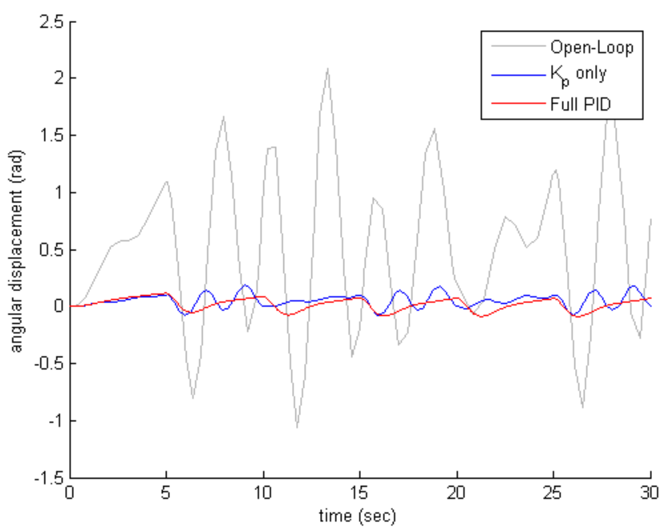


Figure 10.7: The time responses of all simulated parameters. Open-loop response in grey, only proportional in blue, and full PID in red.

overshoot, the path of the AIRWT around a vine would be closer to the trunk, thereby allowing more precise cutting with reduced possibility of missing weeds.

Chapter 11

Engineering Standards and Realistic Constraints

11.1 Ethics

Our group's ethical justification for the AIRWT project was that it would provide an environmentally cleaner and cheaper method for removing weeds in vineyards on hillsides, which could then be potentially applied to other types of crops.

The primary ethical concern for the final product was ensuring that no one was in serious danger of being injured by any portion of the machine while it was in operation and everyone around the device was following safe operating procedures.

As for ethics regarding the team itself, the work amongst the members were split as evenly and fairly as possible, as all projects and deliverables were viewed as collaborative efforts, with the expectation that all team members will contribute and assist in driving the project to a successful resolution. The activity reports completed at the end of each week were used to judge each team members' performance and level of involvement in the project; any notable disproportionality in team members hours vested into the project were subject to review by the team leaders, who could elect to leverage penalties or increase the workload of an offender if the member failed to contribute an appropriate amount. If the subject felt the punishment was too severe, he or she could discuss it with other members of the team, and with a majority ruling have the punishment lessened or completely removed. Fortunately, there were no incidents of major workload imbalance. All members put in the amount of work expected of them.

11.2 Economics

The ultimate goal of the Automated In-Row Weed Trimmer is to decrease the need for manual labor and herbicides to eliminate weeds in hillside vineyards. For the vineyard owner, this reduction in manual labor and herbicide correlates directly to saving money every year weeds must be removed, and would allow for small, organic vineyard owners to breach the upper tiers of automated farming.

11.2.1 Front-Load Costs

The cost to purchase the AIRWT system, should it be mass-produced, is estimated to be about $3000. This front-load cost would be significantly lower than the AIRWTs closest competitor– the in-row tiller, which can cost anywhere from $4,500 (the Goldoni Star 3080) to $20,000 (the Tournesol).Based on this, the upfront cost of using the AIRWT system would range from 92.5% to 66% cheaper than its current competitors. The prototype AIRWT system currently costs roughly $2,000. This figure will be used as a worst case cost comparison as this current sum accounts for parts that have been purchased but not used.

11.2.2 Manufacturing Costs

The assembly of the prototype AIRWT system is estimated to require five people working non-stop for four hours. If the hourly rate is assumed to be $25.00 per hour, the net cost for constructing the AIRWT system sums to $1,500.

11.2.3 Operational Costs

According to the Aver Family Vineyard, weeding requires a total of seven workers, working four days a week for three weeks. Assuming a full 8-hour work day at a rate of $8.00 per hour, the total operational cost is $5,376. With the AIRWT system, it is assumed that only one worker will need to work for the 12-day period. Over this period, the linear actuator will consume 288 Ah

(3 A/hr for 8 hr/day over 12 days) and the trimmer is assumed to consume 144 Ah (1.5 A/hr over the same period). At 12 V and 18 V, respectively, these equate to 3.456 and 2.592 kWh. Given the average commercial electricity rate of Gilroy (the location of the Aver Family Vineyard) of $0.1408/kWh, the comparative operational cost is $769, which is about an 85% cost reduction.

11.3 Environmental

The EPA has released standards for tractor emissions of various sizes. Assuming the tractors used in vineyards are of the smallest kind to fit in the rows, the CO_2 standard for an equivalent vehicle for our product would be 107 g/ton-mile. Further assuming a tractor of 26000 lbs, or 13 tons, the CO_2 emission is 1391 g/mile. As will be shown in the following section, this greatly overcomes the CO_2 emitted by the electrical components used for our project.

Table 11.1: CO_2 Standards for Vocational Vehicles. Obtained from EPA 1037.106.[6]

GVWR (pounds)	Sub-Category	CO_2 Standards (g/ton-mile) for Model Years 2014-2016	CO_2 Standards (g/ton-mile) for Model Year 2017 and later
26,000<GVWR ≤ 33,000	Low-Roof (All Cab Styles)	107	104
	Mid-Roof (All Cab Styles)	119	115
	High Roof (All Cab Styles)	124	120
GVWR>33,000	Low-Roof Day Cab	81	80
	Low-Roof Sleeper Cab	68	66
	Mid-Roof Day Cab	88	86
	Mid-Roof Sleeper Cab	76	73
	High-Roof Day Cab	92	89
	High-Roof Sleeper Cab	75	72

Based on emissions data provided by the EPA, the team has determined that 115 grams of carbon dioxide will be emitted in one full discharge cycle of the system. It should be noted that the carbon dioxide will be emitted from the power plant from which the AIRWT system will draw its electric charge. Alternative clean sources of energy (i.e., wind, solar, and water) may be used for future iterations to achieve true zero carbon footprint.

The calculations to determine the amount of CO_2 emitted per discharge cycle were performed with the following facts: 6.89551 10-4 metric tons CO_2 is discharged per kWh of a power plant. [kWh] = [Amp-hour] * Volts

By knowing that the trimmer battery was rated at 18 V and 1300 mAh, and the linear actuator battery is rated at 12 V and 12 Ah, it was determined that 115g of CO_2 will be emitted per charge of the AIRWT system.

11.4 Manufacturability

The product is currently hand built, but it is assumed that with enough commercial success, say at least about $50,000 profit, the manufacturing of the product could be moved from a hand-built setting to a factory. This would likely speed up the production of the product, since no development time issues are predicted to arise. However, the cost of an individual unit may rise by about $25 if the wood parts used in the original design were replace with metal pieces.

11.5 Usability

The usability of the AIRWT played a big part in how the system was designed, as the team wanted the AIRWT to be easy to operate in order to allow for a widespread use. While it is an autonomous system, the user should ideally only need to attach or remove a cutting head, flip an on and off switch, and change the battery once the power runs out. Lastly, the team wanted the system to be simple to maintain and fix should a problem arise, so almost of the components of the device were standardized and could be bought in a store to fix any damaged components.

11.6 Sustainability

It is expected that the AIRWT product will have an operational lifespan of at least 7 to 10 years before a key component irreparably breaks. This is expected to be most likely the linear actuator component of the machine considering all of the complex components within it. The only parts that would potentially need to be replaced during this operational lifespan is expected to be the nylon string for the cutting head and the batteries used by the current model. The current lead-acid battery should last about 2.5 to 5 years in conditions it shall be working in before needing to be replaced, but it is expected that this need to replace the battery will be essentially eliminated once the design incorporates a rechargeable lithium ion battery, eliminating the need to buy new ones.

11.7 Health and Safety

In the designing of this project, the AIRWT team sought to use engineering in a way that improves the current condition of the way weeds are handled in vineyards for both humans and the environment. With this idea, health and safety play a major role in the engineering of products. The AIRWT team has taken from past failures in engineering to learn how paramount the design of the AIRWT system is. Therefore, throughout the design of this project, the team anticipated some of the major health and safety factors for the Automated In-Row Weed Trimmer would be with regards to moving mechanical components and the electrical components.

For moving mechanical components, the AIRWT system has a weed-whacker head that is powered by a motor to rotate the nylon cutting line. This cutting head has a cover to prevent immediate harm, and there is a kill-switch located near the control box to shut down the machine. The linear actuator used to extend the arm is powered by a gearbox, but since it is covered there shouldn't present any issue while the the device is running. However, if repairs need to be made to it, the power source must be turned off and should be disconnected to ensure safety. Since the wheels on the cart itself will also rotating when moving the device, be completely aware of your surroundings while wheeling the device. Lastly, in order to ensure safety, all individuals near the device should be wearing eye protection while it is in operation.

As for the electrical aspect of this project, there will be a central electronic control center, which will control the motion of the arm and when the blade activates it. If ever a problem should arise involving the electronics, there is a kill-switch implemented into the machine to completely cut the power. The electrical systems of this project must only be operated on when the power supply is disconnected in order to prevent electrocution. As a further precaution, all electrical connections are insulated to further prevent the risk of electrocution during operation. Lastly, it is advised that the operator wears gloves while directly working with the electronics in order to ensure safety.

11.8 Arts

As a part of satisfying the SCU Core Arts and Humanities requirements, members of this team have all contributed original drawings, sketches, and/or CAD models and drawings to this project. Below in Table 11.2 is a list detailing a sample of each member's contributions and their location within this thesis document.

Table 11.2: Art requirement contributions of each group member.

Team Member	**Description**	**Location**
Joshua Baculi	CAD of Sensor Arm Assembly	Figure 6.1
Tyler Castrucci	Grounding plate for the electronics	Figure A.5
Joshua Ding	Early concept Generation	Figure M.2
Marit Knapp	Early concept generation	Figure 2.2
Gaston Young	Early concept generation	Figure M.1

Chapter 12

Conclusion

12.1 Evaluation of Design

The team fully understands that the extent which this prototype has reached is a mere proof of concept and that there are opportunities for revision and improvement. Given the time constraint, the current state of the product is what the team could realistically achieve given the product goals.

With that said, through preliminary testing and evaluation procedures, the system has achieved performance within the final and target specifications. As a result, the team can deem this system as effective and efficient at its goal of (semi) automating weed removal operations at vineyards in a cost effective and environmentally friendly manner.

At no point throughout these testing procedures did any components fail or exhibit signs of possible failure, indicating that components were chosen and manufactured properly.

12.2 Future Improvements

Notably, one of the major features lacking in this iteration of the AIRWT system is an autonomous mounting vehicle. As previously explained, the time constraints prevented the team from developing a full-fledged autonomous solution. But it is the team's hope that future product development cycles will address this issue and deliver a fully autonomous go to market solution.

While this particular customer will only deploy the AIRWT in dry environments, the team foresees possible concerns with durability and reliability with the wooden mounting plate, wooden base deck, and exposed electronic components. In future iterations, the team hopes to fully enclose all electronic components and run all wiring through extendable tubes/channels as to reduce the risk of damage via weathering an interference by foreign objects. In addition, the team wishes to use heavy-duty materials for the mounting plate and base deck to promote robustness and longevity.

The linear actuator was selected based on its power capabilities, based on the shift away from a large, industrial design to a smaller more agile model, the selection of linear actuator would be based on its retraction and extension speed. Therefore, a high speed linear actuator built by Firgelli Automations would serve the AIRWT system better. These linear actuators have a variety of stroke lengths and can operate at up to 9 inch per second with no load. The full specification of the Firgelli Automations high speed linear actuators are in Appendix G, Figures G.1 and G.2.

The Edison microprocessor implemented in the AIRWT is an incredibly capable unit, and the team believes that it has not fully harnessed the power of this microprocessor. As all markets seem to be placing a higher emphasis on Big Data and the Internet of Things, the team wishes to include the following electronic features in future revisions of the AIRWT:

1. Self-diagnosing capability
    (a) The AIRWT is able to automatically detect impending component failures and notify supervisors to perform remedial action. This will ensure that the AIRWT is always in proper maintenance and will reduce the risk of a catastrophic component/system failure.
2. Self-correcting capability
    (a) A self-correcting capability will enable the AIRWT system to adjust its course in the event it encounters an unforeseen obstacle and continue weed removal operations. This will limit downtime and need for excessive system supervision.
3. Self-terminating capability

(a) In the event that the AIRWT system does perform a catastrophic operation (damage a vine, experience complete component/system failure, etc.), it should be able to cease all operations automatically. This ability should reduce the need for excessive system supervision and ensure limited damage to the vineyard.

12.3 Lessons Learned

One of the major difficulties encountered during this product development process was communicating with the customer. Unfortunately, the team was unable to contact the customer until three months into a nine month product development process. Assumptions that the team had made in the three months eventually turned out to be inaccurate, and necessitated that the team repeat the front end process. Effectively, the AIRWT system was conceived, designed, and developed in a six month product development cycle; given the complexity of certain subsystems, this was not an easy feat.

Of course, the team comprehends that acquiring customer needs is a vital part of the front end process, and more effort should have been exerted in communicating with the customer. However, it is with full faith that the team believes that this first iteration of the AIRWT system will be able to perform admirably in the field and thus marks the success of this product development cycle.

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Appendices

Appendix A

Performance Optimization

The following pages show the system performance characteristics. The capabilities of the system were scored for different concepts. The traits of each capability were ranked based on their level of importance and measurable benchmarks were declared for optimization. This analysis was performed for both the system as a whole and for the individual characteristics.

Project: Automated In-Row Cultivator
System: Whole System
Date: 11/11/2014

	Criterion	1	2	3	4	5	6	7	8	9	10	11	12	SUM	FACTOR
1	Weight		0.8	0.5	0.1	0.5	0.7	0.9	1	0.2				4.7	3
2	Speed	0.2		0.3	0.3	0.4	0.4	0.7	1	0.3				3.6	1
3	Fuel Consumed	0.5	0.7		0.5	0.6	0.4	0.8	1	0.2				4.7	3
4	Accuracy processtole	0.9	0.7	0.5		0.8	0.8	0.9	1	0.5				6.1	4
5	Soil Disturbance	0.5	0.6	0.4	0.2		0.3	0.6	1	0.3				3.9	1
6	Cost	0.3	0.6	0.6	0.2	0.7		0.9	1	0.3				4.6	3
7	Maintenance	0.1	0.3	0.2	0.1	0.4	0.1		1	0.1				2.3	1
8	Noise	0	0	0	0	0	0	0		0				0	0
9	Seedlingspread	0.8	0.7	0.8	0.5	0.7	0.7	0.9	1					6.1	4
10															
11															
12															

Figure A.1: Overall concept prioritizing matrix.

Design Project = Automated In-Row Cultivatc System= Overall Analysis

	TARGET or	DESIGN IDEAS																			
CRITERIA	FACTOR	1 = Baseline		Claw		Oven		Small Rotary		Small Rotary		Rotary		Vacuum Shredder		Single Wheel		Bristle Tiller		Mini dozer	
Time – Design	1	1		2		1		2		2		1		3		2		1		3	
Time – Build	1	1		2		1		2		2		1		2		2		1		3	
Time – Test	1	1		2		1		2		2		1		2		2		1		3	
Time Score	10		10		20.00		10.00		20.00		20.00		10.00		23.33		20.00		10.00		30.00
Cost – Prototype	1	$ 1.00		$ 2.00		$ 1.00		$ 2.00		$ 2.00		$ 1.00		$ 2.00		$ 2.00		$ 1.00		$ 5.00	
Cost – Production	1	$ 1.00		$ 0.50		$ 1.00		$ 0.50				$ 1.00		$ 2.00		$ 0.50		$ 1.00		$ 3.00	
Cost Score	10		10		12.50		10.00		12.50		10.00		10.00		20.00		12.50		10.00		40.00
Weight	3	3	9	4	12	3	9	4	12	4	12	5	15	3	9	5	15	2	6	3	9
Speed	1	3	3	1	1	4	4	1	1	2	2	2	2	5	5	4	4	4	4	4	4
Fuel Consumed	3	3	9	5	15	2	6	4	12	4	12	5	15	2	6	3	9	2	6	3	9
Accuracy, process tolerance	4	3	12	1	4	3	12	1	4	4	16	4	16	3	12	3	12	4	16	5	20
Soil Disturbance	1	3	3	5	5	4	4	4	4	4	4	4	4	3	3	3	3	3	3	3	3
Cost	3	3	9	2	6	3	9	3	9	5	15	5	15	3	9	4	12	2	6	2	6
Maintenance	1	3	3	4	4	3	3	2	2	3	3	3	3	3	3	3	3	3	3	3	3
Noise	0	3	0	3	0	3	0	3	0	3	0	3	0	0	0	0	0	4	0	0	0
Seedling spread	4	3	12	5	20	5	20	4	16	4	16	4.5	18	2	8	3	12	4	16	4	16
0	0	3	0		0		0	1	0		0		0		0		0		0		0
0	0	3	0		0		0	1	0		0		0		0		0		0		0
0	0	3	0		0		0	1	0		0		0		0		0		0		0
	TOTAL		60.0		54.5		67.0		47.5		70.0		88.0		31.7		57.5		60.0		20.0
	RANK																				
	% MAX		68.2%		61.9%		76.1%		54.0%		79.5%		100.0%		36.0%		65.3%		68.2%		22.7%
	MAX	88.0																			

NOTE: User fills in Purple areas, gold areas are calculated or fixed
Light blue areas filled from prioritizing matrix

BASELINE = Weed Badger

Timescore(i)=Timescore(B)*(TD(i)/TD(B) + TB(i)/TB(B) + TT(i)/TT(B))/3
Costscore(i)=Costscore(B)*(Cprot(i)/Cprot(B) + Cprod(i)/Cprot(B))/2
Total(i) = SUM(Factor(j)*Comparison(i,j)) + (Timescore(B)-Timescore(i)) + (Costscore(B) - Costscore(i))

Comparison(i,j) = 5 if idea "i" is much better than baseline for criteria "j"
Comparison(i,j) = 4 if idea "i" is better than baseline for criteria "j"
Comparison(i,j) = 3 if idea "i" is same as baseline for criteria "j"
Comparison(i,j) = 2 if idea "i" is worse than baseline for criteria "j"
Comparison(i,j) = 1 if idea "i" is much worse than baseline for criteria "j"

Design Idea Descriptions

2 Claw
3 Oven
4 Small Rotary
5 Small Rotary (Telescopic)
6 Rotary (Counterbalance)
7 Vacuum Shredder
8 Single Wheel
9 Bristle Tiller (Swivel)
10 Mini dozer

Figure A.2: Overall concept scoring.

Project: AIRWT
System: Retraction Mechanism
Date: 11/30/2014

	Criterion	1	2	3	4	5	6	7	8	9	10	11	12	SUM	FACTOR
1	Weight		0	1	0	0.5	0							1.5	
2	Speed	1		1	0.5	1	0							3.5	
3	Maintenance	0.5	0		0.5	0	0							1	
4	Response time	1	0.5	1		1	0							3.5	
5	Size	0.5	0	1	0		0							1.5	
6	Accuracy	1	1	1	1	1								5	
7														0	
8														0	
9														0	
10														0	
11														0	
12														0	

6/8/2015

Figure A.3: Platform motion prioritizing matrix.

Design Project = AIRWT **System=** Retraction Mechanism

	TARGET or	DESIGN IDEAS																			
CRITERIA	FACTOR	Baseline		Springs		Belts		Chains		Gears		Hydraulics		Pneumatics							
Time – Design	3	3		3		3		3		4		3		3							
Time – Build	3	3		2		2		2		3		3		3							
Time – Test	4	4		4		4		4		4		4		4							
Time Score	10		10		8.89		8.89		8.89		11.11		10.00		10.00		0.00		0.00		0.00
Cost – Prototype	1200	$ 1,200.00		$ 200.00		$130.00		$250.00		$400.00		$700.00		$800.00							
Cost – Production	1000	$ 1,000.00		$ 180.00		$117.00		$225.00		$360.00		$630.00		$720.00							
Cost Score	10		10		1.73		1.13		2.17		3.47		6.07		6.93		0.00		0.00		0.00
Weight	3	3	9	4	12	3	9	3	9	2	6	3	9	3	9		0		0		0
Response Time	4	4	16	4	16	5	20	3	12	4	16	2	8	2	8		0		0		0
Maintenance	2	2	4	2	4	2	4	3	6	3	6	3	6	3	6		0		0		0
Speed	4	4	16	4	16	3	12	3	12	3	12	2	8	2	8		0		0		0
Size	3	3	9	3	9	2	6	3	9	4	12	4	12	4	12		0		0		0
Accuracy	5	5	25	1	5	3	15	3	15	4	20	2	10	2	10		0		0		0
0	0	3	0		0		0		0		0		0		0		0		0		0
0	0	3	0		0		0		0		0		0		0		0		0		0
0	0	3	0		0		0		0		0		0		0		0		0		0
0	0	3	0		0		0		0		0		0		0		0		0		0
0	0	3	0		0		0		0		0		0		0		0		0		0
0	0	3	0		0		0		0		0		0		0		0		0		0
	TOTAL		79.0		71.4		76.0		71.9		77.4		56.9		56.1		20.0		20.0		20.0
	RANK																				
	% MAX		100.0%		90.4%		96.2%		91.1%		98.0%		72.1%		71.0%		25.3%		25.3%		25.3%
	MAX	79.0																			

NOTE: User fills in Purple areas, gold areas are calculated or fixed
Light blue areas filled from prioritizing matrix

BASELINE = Linear Actuators

Design Idea Descriptions

2	Springs
3	Belts
4	Chains
5	Gears
6	Hydraulics
7	Pneumatics
8	
9	
10	

Timescore(i)=Timescore(B)*(TD(i)/TD(B) + TB(i)/TB(B) + TT(i)/TT(B))/3
Costscore(i)=Costscore(B)*(Cprot(i)/Cprot(B) + Cprod(i)/Cprot(B))/2
Total(i) = SUM(Factor(j)*Comparison(i,j)) + (Timescore(B)-Timescore(i)) + (Costscore(B) - Costscore(i))

Comparison(i,j) = 5 if idea "i" is much better than baseline for criteria "j"
Comparison(i,j) = 4 if idea "i" is better than baseline for criteria "j"
Comparison(i,j) = 3 if idea "i" is same as baseline for criteria "j"
Comparison(i,j) = 2 if idea "i" is worse than baseline for criteria "j"
Comparison(i,j) = 1 if idea "i" is much worse than baseline for criteria "j"

Figure A.4: Platform motion concept scoring.

Project: Automated In-Row Cultivator
System: Proximity Detection
Date: 13-Nov-14

	Criterion	1	2	3	4	5	6	7	8	9	10	11	12	SUM	FACTOR
1	Weight		0.3	0	0.3	0.3	0.5	0.4	0.2					2	2
2	Speed	0.7		0.5	0.7	0.8	0.8	0.7	0.4					4.6	5
3	Accuracy	1	0.5		0.6	0.8	1	0.7	0.5					5.1	5
4	Cost	0.7	0.3	0.4		0.5	0.8	0.6	0.3					3.6	4
5	Durability	0.7	0.2	0.2	0.5		0.8	0.4	0.3					3.1	3
6	Aesthetics	0.5	0.2	0	0.2	0.2		0.1	0					1.2	1
7	Power Consumption	0.6	0.3	0.3	0.4	0.6	0.9		0.2					3.3	3
8	Effect on Vines	0.8	0.6	0.5	0.7	0.7	1	0.8						5.1	5
9															
10															
11															
12															

Figure A.5: Detection concept prioritizing matrix.

Design Project = Automated In-Row Cultivatc **System=** Proximity Detection

CRITERIA	TARGET or FACTOR	1 = Baseline		GPS		Visual Recognition		Thermal		Proximity Sensor											
		DESIGN IDEAS																			
Time – Design	3	3		1		1		2		2											
Time – Build	3	3		2		3		3		2											
Time – Test	3	3		3		3		2		2											
Time Score	10		10		6.67		7.78		7.78		6.67		0.00		0.00		0.00		0.00		0.00
Cost – Prototype	1	$ 1.00		$ 3.00		$ 4.00		$ 3.50		$ 3.00											
Cost – Production	1	$ 1.00		$ 2.00		$ 3.00		$ 3.00		$ 2.00											
Cost Score	10		10		25.00		35.00		32.50		25.00		0.00		0.00		0.00		0.00		0.00
Weight	2	3	6	3	6	3	6	3	6	3	6		0		0		0		0		0
Speed	5	3	15	2	10	1	5	2	10	3	15		0		0		0		0		0
Accuracy	5	3	15	2	10	3	15	3	15	2	10		0		0		0		0		0
Cost	4	3	12	1	4	1	4	1	4	2	8		0		0		0		0		0
Durability	3	3	9	3	9	2	6	2	6	3	9		0		0		0		0		0
Aesthetics	1	3	3	4	4	4	4	4	4	3	3		0		0		0		0		0
Power Consumption	3	3	9	2	6	2	6	2	6	2	6		0		0		0		0		0
Effect on Vines	5	3	15	4	20	4	20	4	20	4	20		0		0		0		0		0
0	0	3	0		0		0				0		0		0		0		0		0
0	0	3	0		0		0				0		0		0		0		0		0
0	0	3	0		0		0				0		0		0		0		0		0
0	0	3	0		0		0				0		0		0		0		0		0
	TOTAL		84.0		57.3		43.2		50.7		65.3		20.0		20.0		20.0		20.0		20.0
	RANK																				
	% MAX		100.0%		68.3%		51.5%		60.4%		77.8%		23.8%		23.8%		23.8%		23.8%		23.8%
	MAX	84.0																			

NOTE: User fills in Purple areas, gold areas are calculated or fixed
Light blue areas filled from prioritizing matrix

BASELINE = Weed Badger Sensor Arm

Timescore(i)=Timescore(B)*(TD(i)/TD(B) + TB(i)/TB(B) + TT(i)/TT(B))/3
Costscore(i)=Costscore(B)*(Cprot(i)/Cprot(B) + Cprod(i)/Cprot(B))/2
Total(i) = SUM(Factor(j)*Comparison(i,j)) + (Timescore(B)-Timescore(i)) + (Costscore(B) - Costscore(i))

Comparison(i,j) = 5 if idea "i" is much better than baseline for criteria "j"
Comparison(i,j) = 4 if idea "i" is better than baseline for criteria "j"
Comparison(i,j) = 3 if idea "i" is same as baseline for criteria "j"
Comparison(i,j) = 2 if idea "i" is worse than baseline for criteria "j"
Comparison(i,j) = 1 if idea "i" is much worse than baseline for criteria "j"

Design Idea Descriptions

2 Pre-programmed GPS path - knows where the vines are beforehand and avoids them
3 Visual Imaging Recognition - matches up weeds with preprogrammed weed image
4 Thermal Imaging Detector - detects and hones in on thermal ID of weeds
5 Proximity Detector - detects nearby vines with some sort of reverse motion type sensor
6 six
7 seven
8 eight
9 nine
10 ten

Figure A.6: Detection concept scoring.

Project: Automated Weed Whacker
System: Power System
Date: Nov. 13th 2014

	Criterion	1	2	3	4	5	6	7	8	9	10	11	12	SUM	FACTOR
1	Weight		0.5	1	1	1	0.4							3.9	3
2	output power	0.5		1	1	1	0.8							4.3	3
3	noise	0	0		0.1	0	0							0.1	1
4	extra equip(tank, solarcell	0	0	0.9		0.2	0.2							1.3	1
5	output/pollution	0	0	1	0.8		0.2							2	1
6	cost	0.6	0.2	1	0.8	0.8								3.4	2

Fill in Purple squares above

Fill in upper triangle of the matrix

Working across each row, determine if the criterion in that row is more important (1), same importance (0.5) or less important (0) than the criterion in that column

Figure A.7: Power source prioritizing matrix.

Design Project = Automated Weed Whacker **System=** Power

	TARGET or	DESIGN IDEAS																			
CRITERIA	FACTOR	1 = Baseline		gas 4 stroke engine		battery		photovoltaics/batter		POT											
Time – Design	5	5		5		5		3		7											
Time – Build	5	5		5		5		2		7											
Time – Test	5	5		5		5		5		7											
Time Score	10		10		10.00		10.00		6.67		14.00		0.00		0.00		0.00		0.00		0.00
Cost – Prototype	1	$ 1.00		$ -		$ -		$ -		$ -											
Cost – Production	300	$ 300.00		$ 300.00		$ 70.00		$200.00		$ 20.00											
Cost Score	10		10		5.00		1.17		3.33		0.33		0.00		0.00		0.00		0.00		0.00
Weight	3	3	9	3	9	7	21	5	15	10	30		0		0		0		0		0
output power	3	8	24	8	24	7	21	2	6	8	24		0		0		0		0		0
noise	1	3	3	3	3	10	10	10	10	4	4		0		0		0		0		0
extra equip(tank, solarcell)	1	2	2	2	2	10	10	7	7	10	10		0		0		0		0		0
output/pollution	1	1	1	2	2	8	8	7	7	5	5		0		0		0		0		0
cost	2	5	10	5	10	7	14	4	8	9	18		0		0		0		0		0
	TOTAL		49.0		55.0		92.8		63.0		96.7		20.0		20.0		20.0		20.0		20.0
	RANK																				
	% MAX		50.7%		56.9%		96.0%		65.2%		100.0%		20.7%		20.7%		20.7%		20.7%		20.7%
	MAX	96.7																			

NOTE: User fills in Purple areas, gold areas are calculated or fixed
Light blue areas filled from prioritizing matrix

BASELINE = 2 stroke engine

Design Idea Descriptions

2 two
3 three
4 four
5 five
6 six
7 seven
8 eight
9 nine
10 ten

Timescore(i)=Timescore(B)*(TD(i)/TD(B) + TB(i)/TB(B) + TT(i)/TT(B))/3
Costscore(i)=Costscore(B)*(Cprot(i)/Cprot(B) + Cprod(i)/Cprot(B))/2
Total(i) = SUM(Factor(j)*Comparison(i,j)) + (Timescore(B)-Timescore(i)) + (Costscore(B) - Costscore(i))

Comparison(i,j) = 5 if idea "i" is much better than baseline for criteria "j"
Comparison(i,j) = 4 if idea "i" is better than baseline for criteria "j"
Comparison(i,j) = 3 if idea "i" is same as baseline for criteria "j"
Comparison(i,j) = 2 if idea "i" is worse than baseline for criteria "j"
Comparison(i,j) = 1 if idea "i" is much worse than baseline for criteria "j"

Figure A.8: Power source concept scoring.

Appendix B

Detail and Assembly Drawings

The following pages show the detail drawings of all the custom fabricated parts of the AIRWT system. The 3D CAD models were built in Solidworks and so the 2D detail drawings were also conducted in Solidworks.

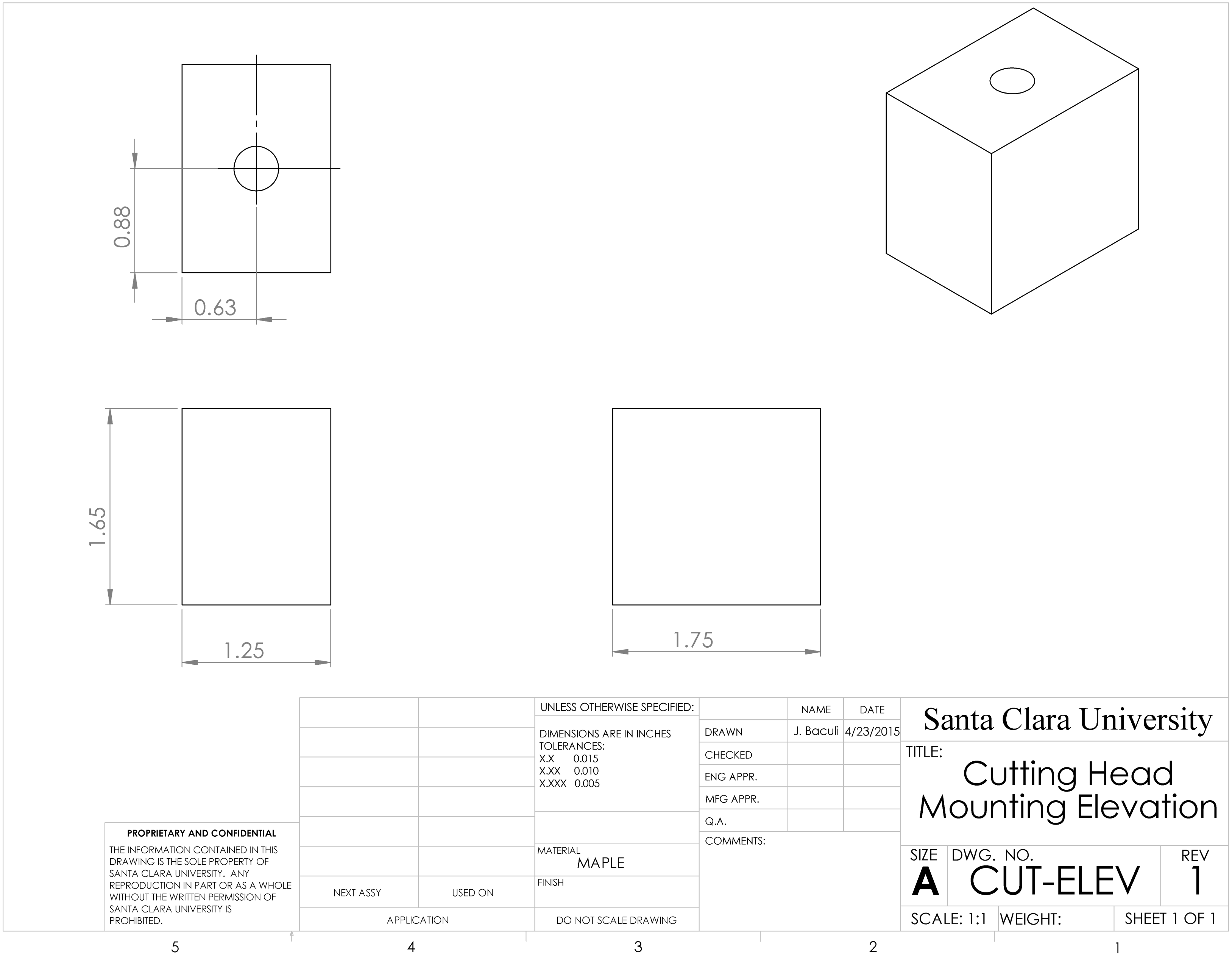


Figure B.1: Elevation block for the cutting head mounting assembly.

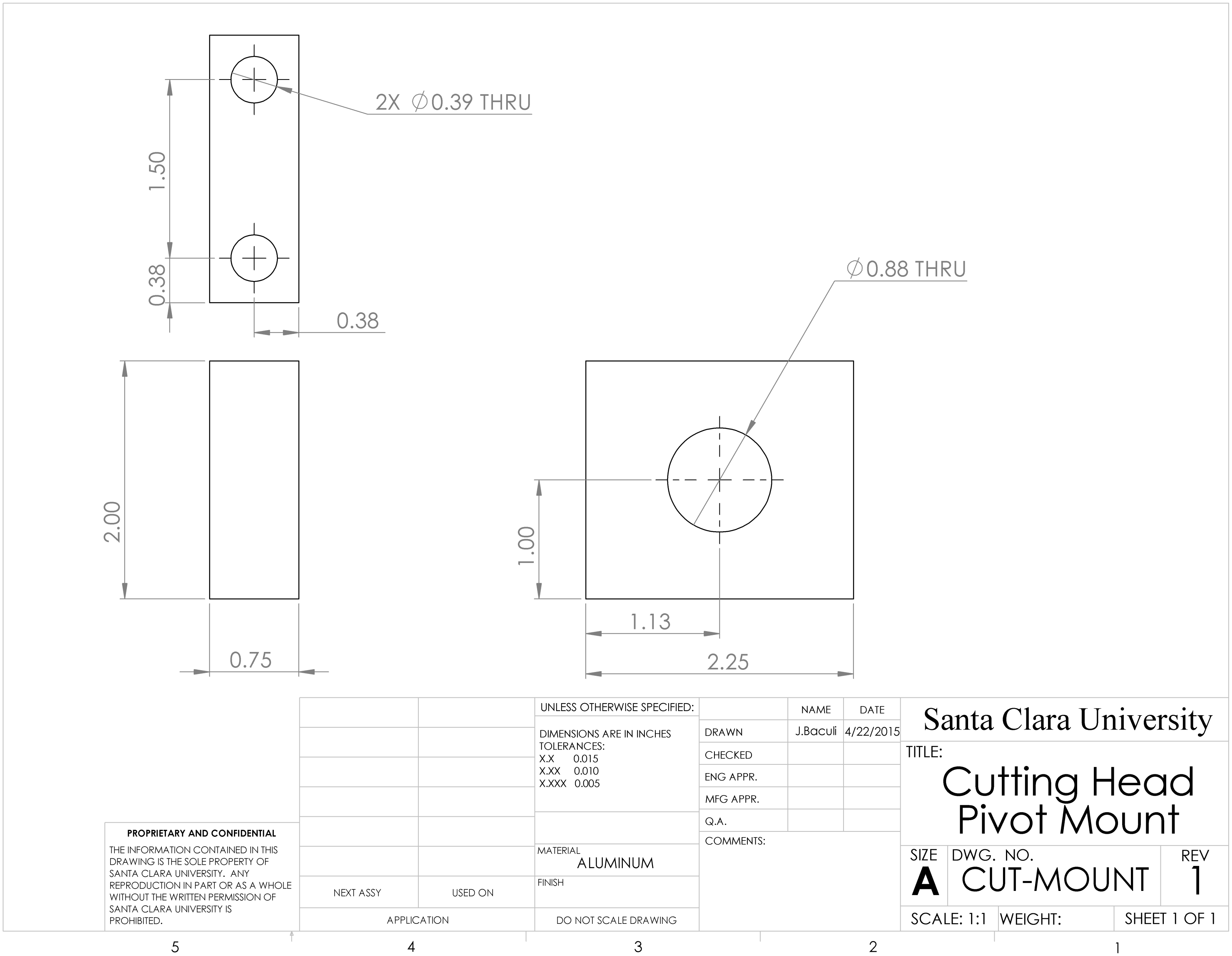


Figure B.2: Pivot mount that goes into the disassembled cutting head to fix it in place.

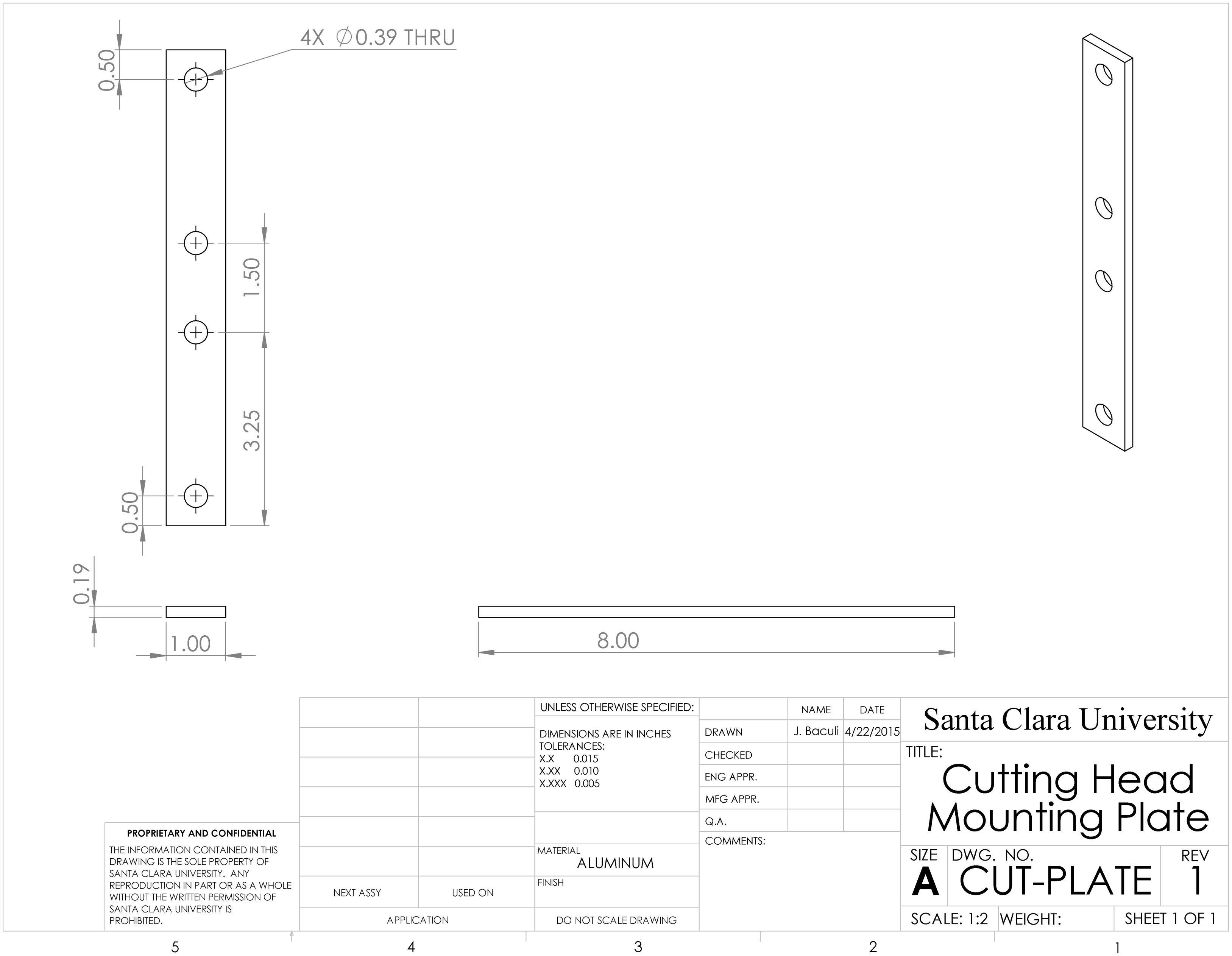


Figure B.3: Adapter plate that connects the Cutting Head.

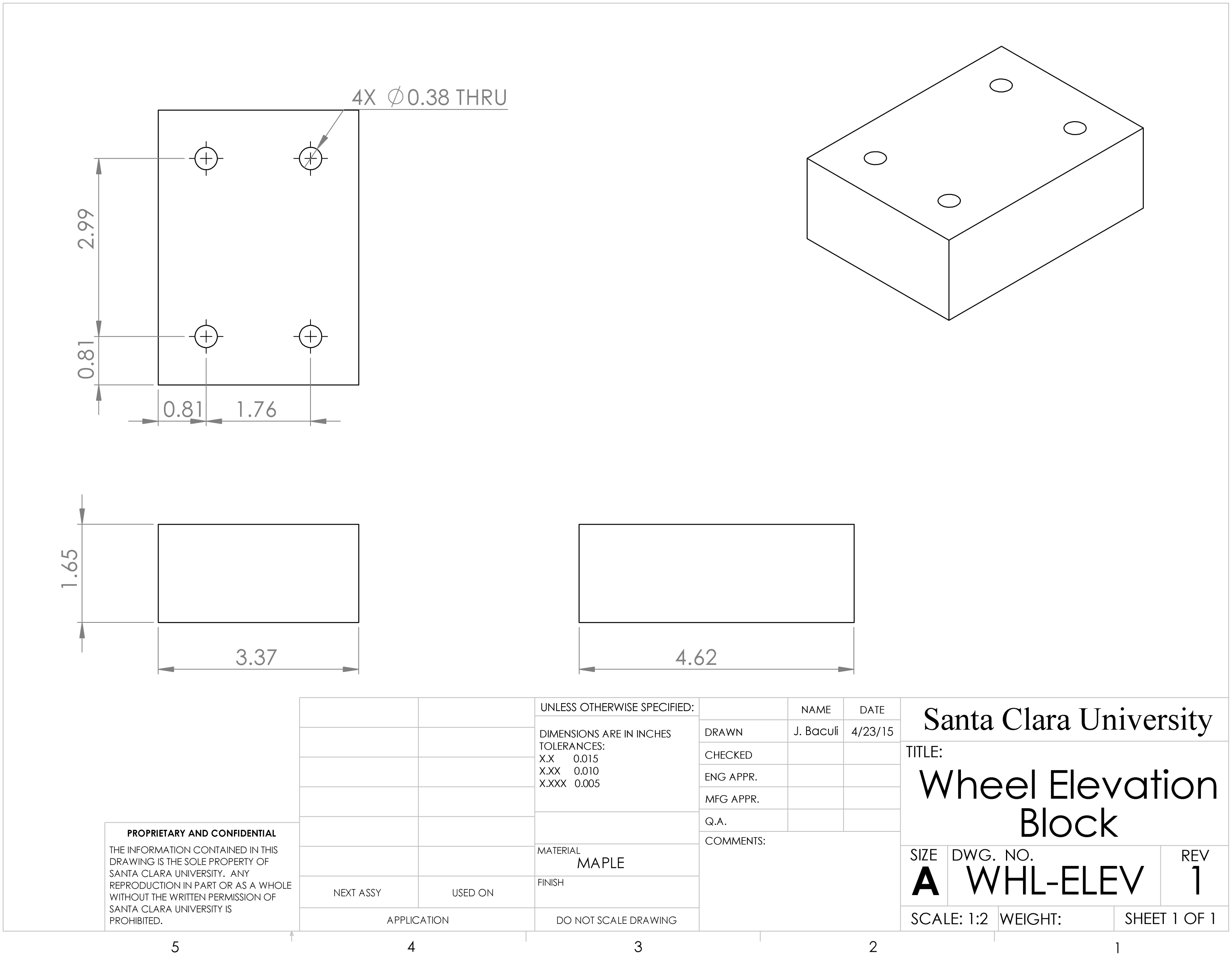


Figure B.4: Elevation block between the caster wheels and the mounting plate to raise the overall height of the cutting mechanism.

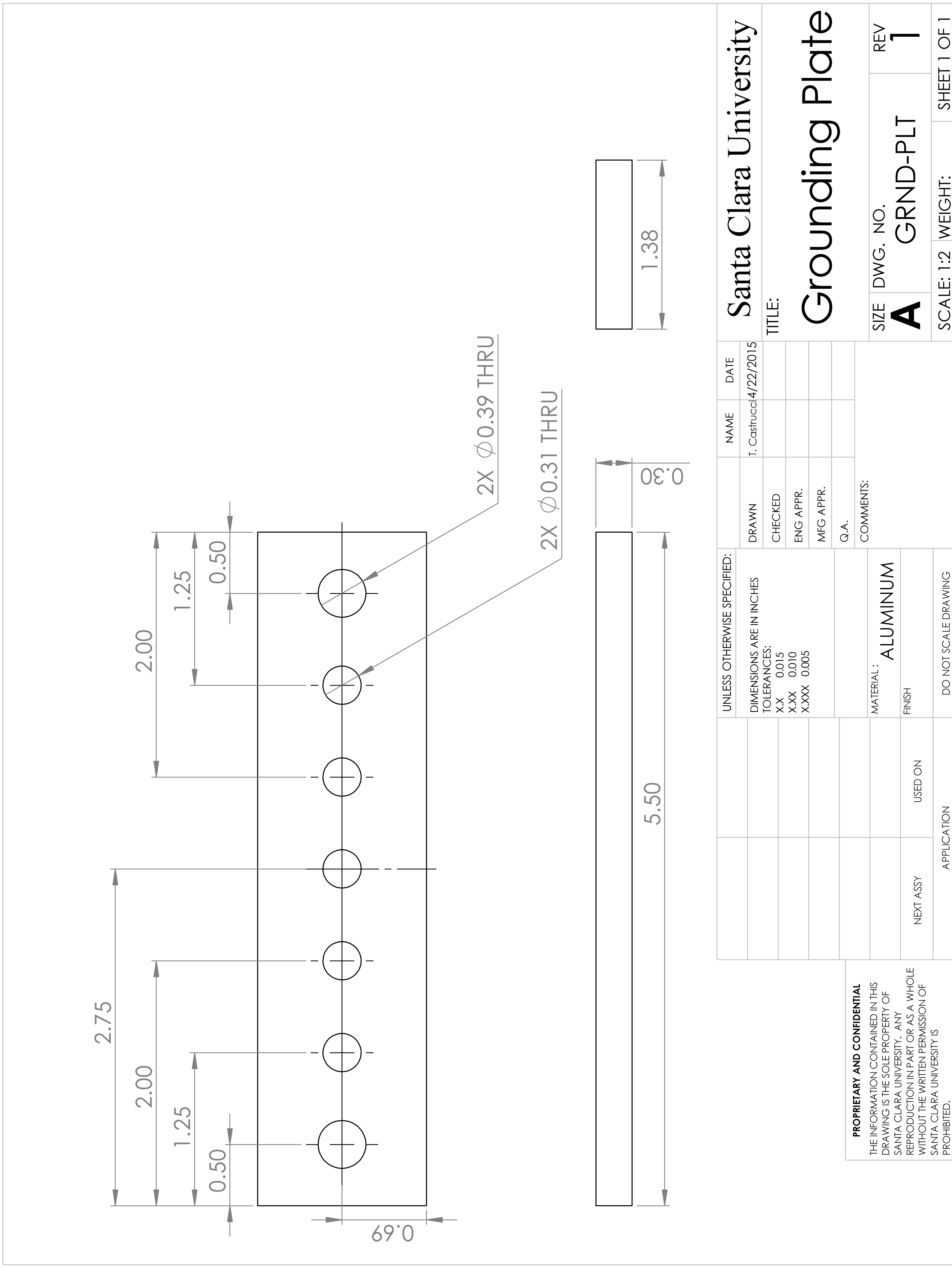


Figure B.5: Grounding plate for the electronics.

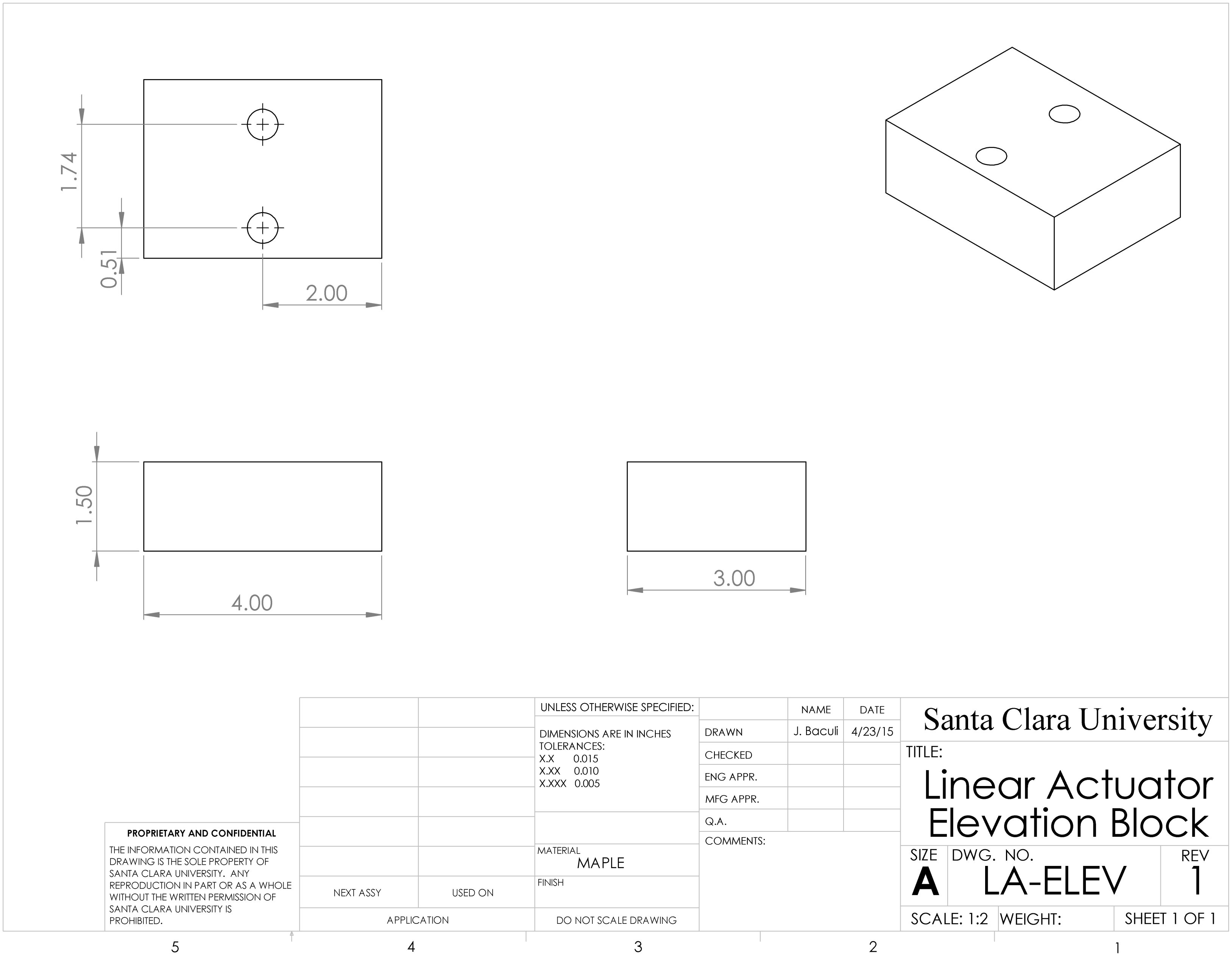


Figure B.6: Elevation block between the fixed end of the linear actuator and the cart deck to increase the angle of mobility of the system.

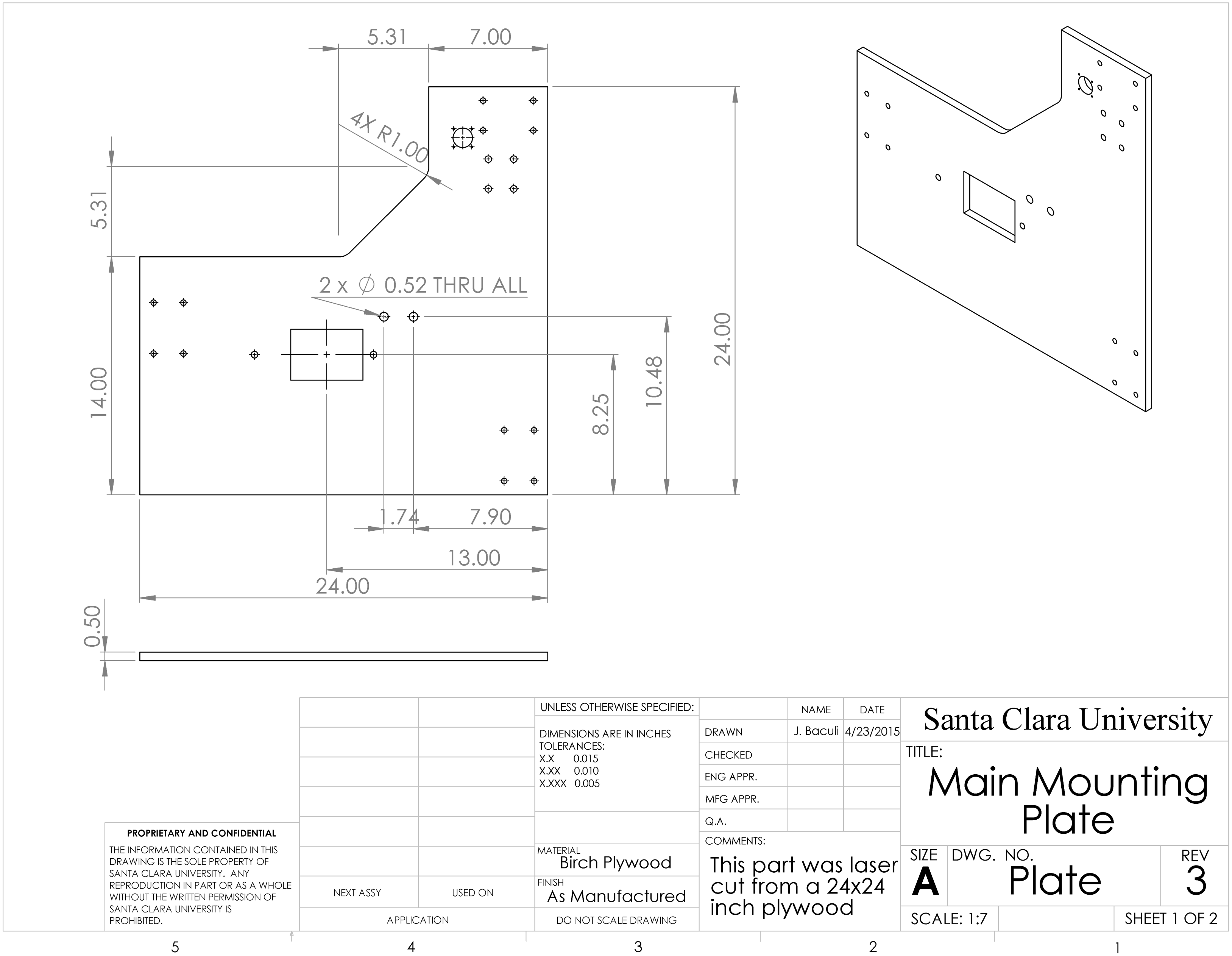


Figure B.7: Mounting plate that contains the cutting head, sensor arm assembly, caster wheels, and linear actuator arm. This sheet shows the overall dimensions of the part and the location of the linear actuator mount.

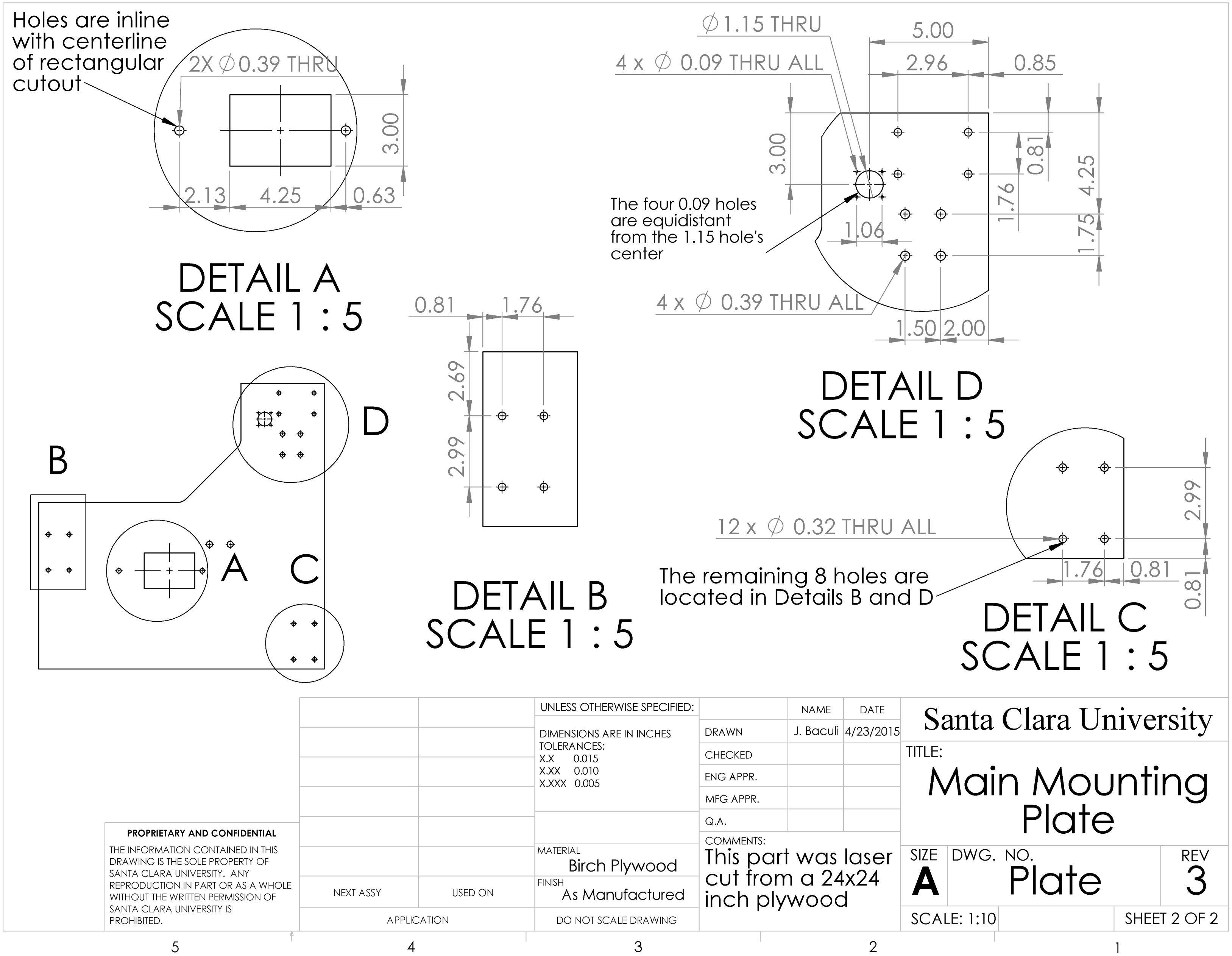


Figure B.8: Mounting plate that contains the cutting head, sensor arm assembly, caster wheels, and linear actuator arm. This sheet shows the detailed locations of the caster wheel holes, cutting head, and sensor arm assembly.

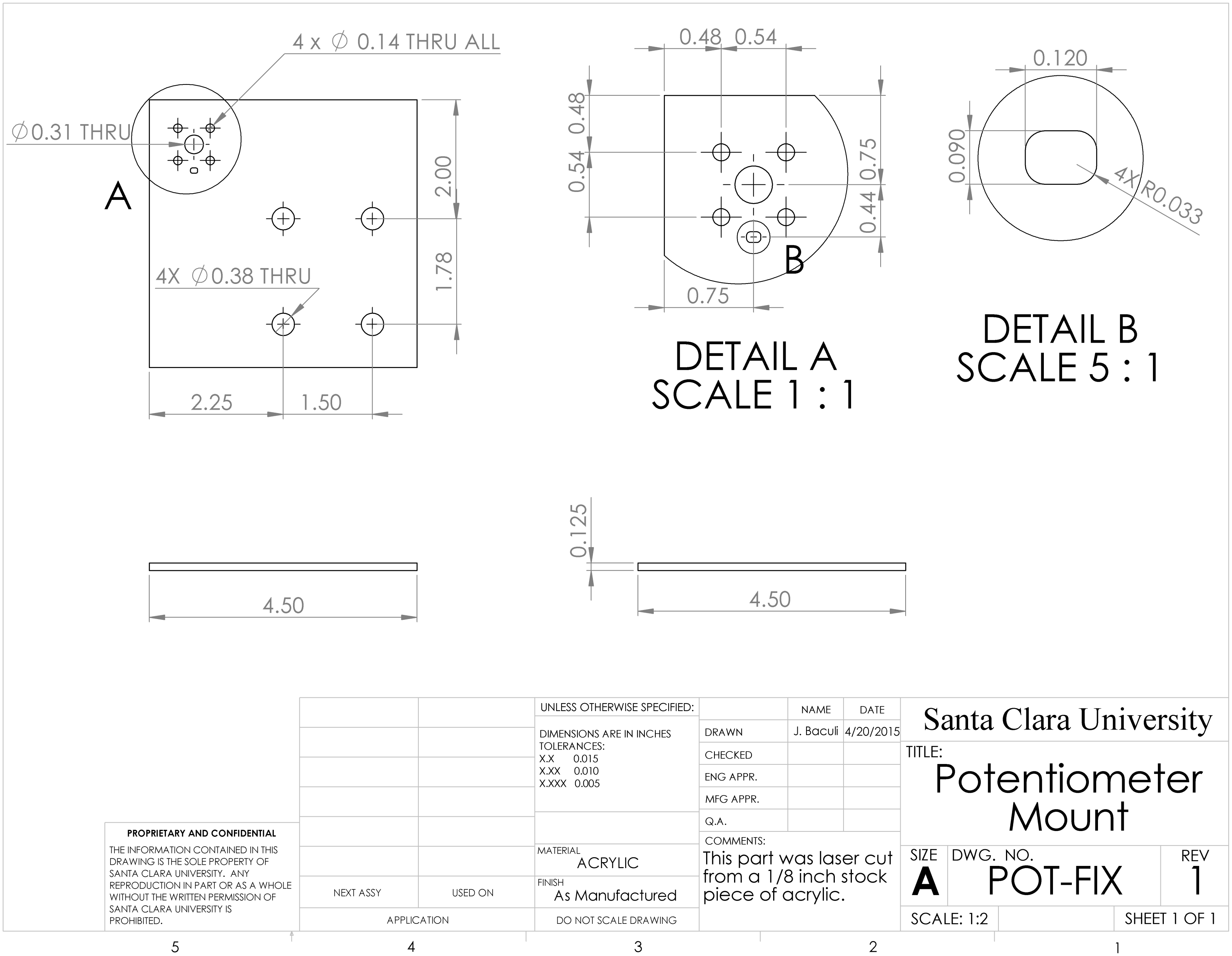


Figure B.9: Acrylic plate that fixes the potentiometer location relative to the stopping block.

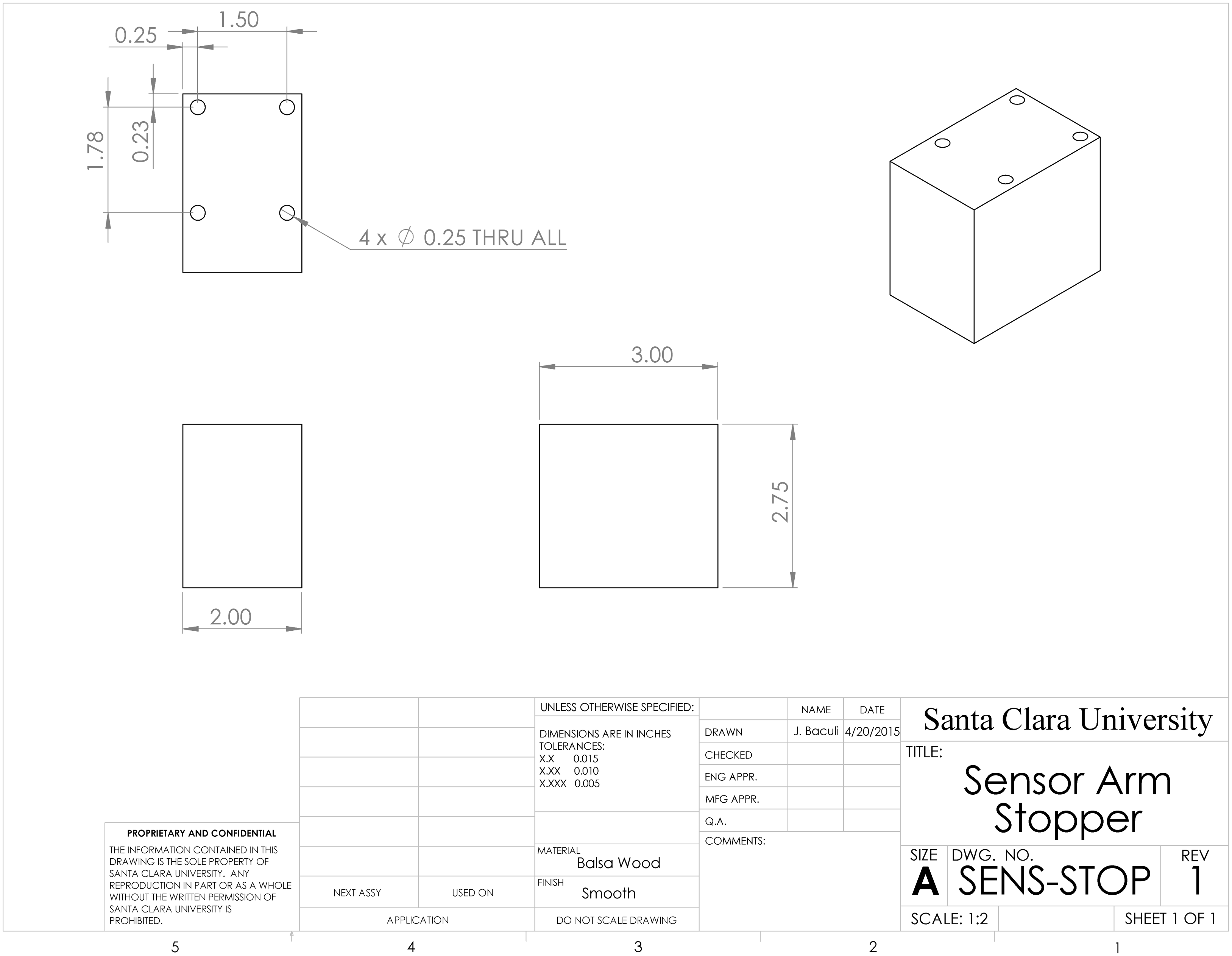
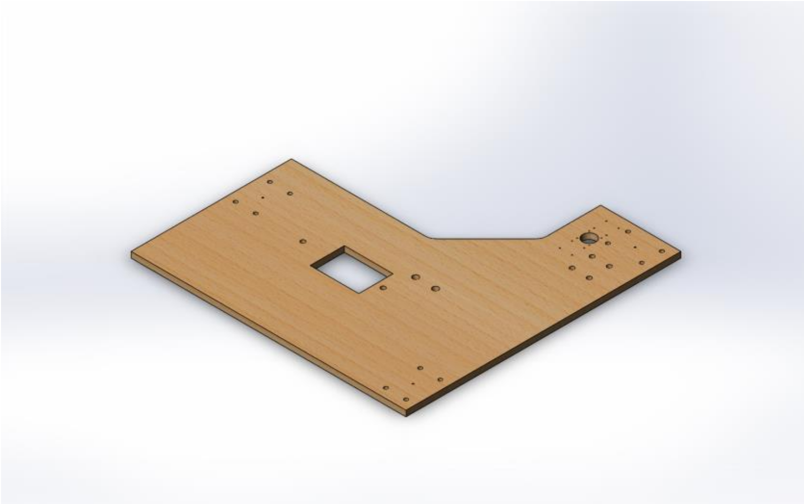


Figure B.10: Stopping block that maintains a fixed neutral location for the sensor arm to return to.

Appendix C

Theoretical Calculations and Simulations

The following pages contain the Finite Element Analyses and MATLAB Simulink models conducted for the AIRWT system. Also included are the hand calculations used to derive the equations of motion for the Simulink models.



Simulation of MountingPlate

Date: Thursday, May 14, 2015
Designer: Solidworks
Study name: SimulationXpress Study
Analysis type: Static

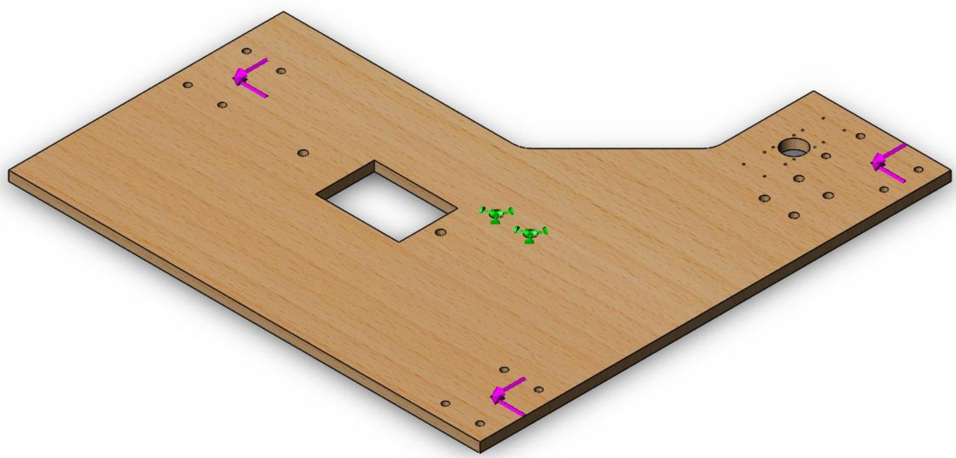
Table of Contents

Description

No Data

Assumptions

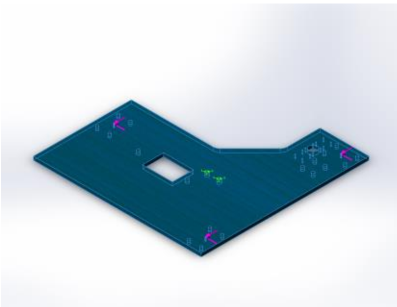
Model Information



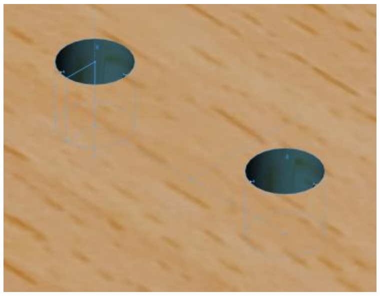
Model name: MountingPlate
Current Configuration: Default

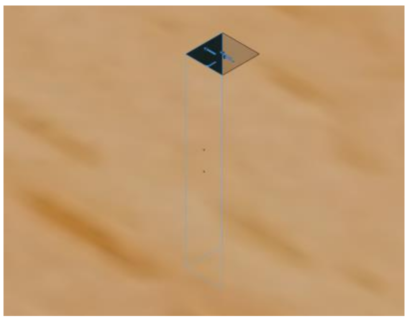
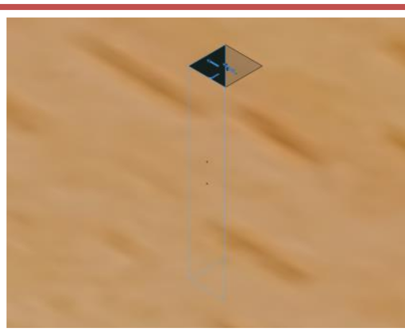
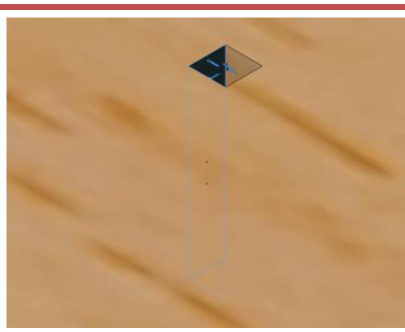
Solid Bodies			
Document Name and Reference	**Treated As**	**Volumetric Properties**	**Document Path/Date Modified**
Cutting Head Opening 	Solid Body	**Mass:0.527017 kg** **Volume:0.00329407 m^3** **Density:159.99 kg/m^3** **Weight:5.16477 N**	**\\samba1\jbaculi\dcengr\Desktop\Undergrad\Senior Design\Sensor Arm Assembly\MountingPlate.SLDPRT** May 13 13:31:49 2015

Material Properties

Model Reference	Properties	Components
	**Name:** Balsa **Model type:** Linear Elastic Isotropic **Default failure criterion:** Unknown **Yield strength:** 2e+007 N/m^2	SolidBody 1(Cutting Head Opening)(MountingPlate)

Loads and Fixtures

Fixture name	Fixture Image	Fixture Details
Fixed-2		**Entities:** 2 face(s) **Type:** Fixed Geometry

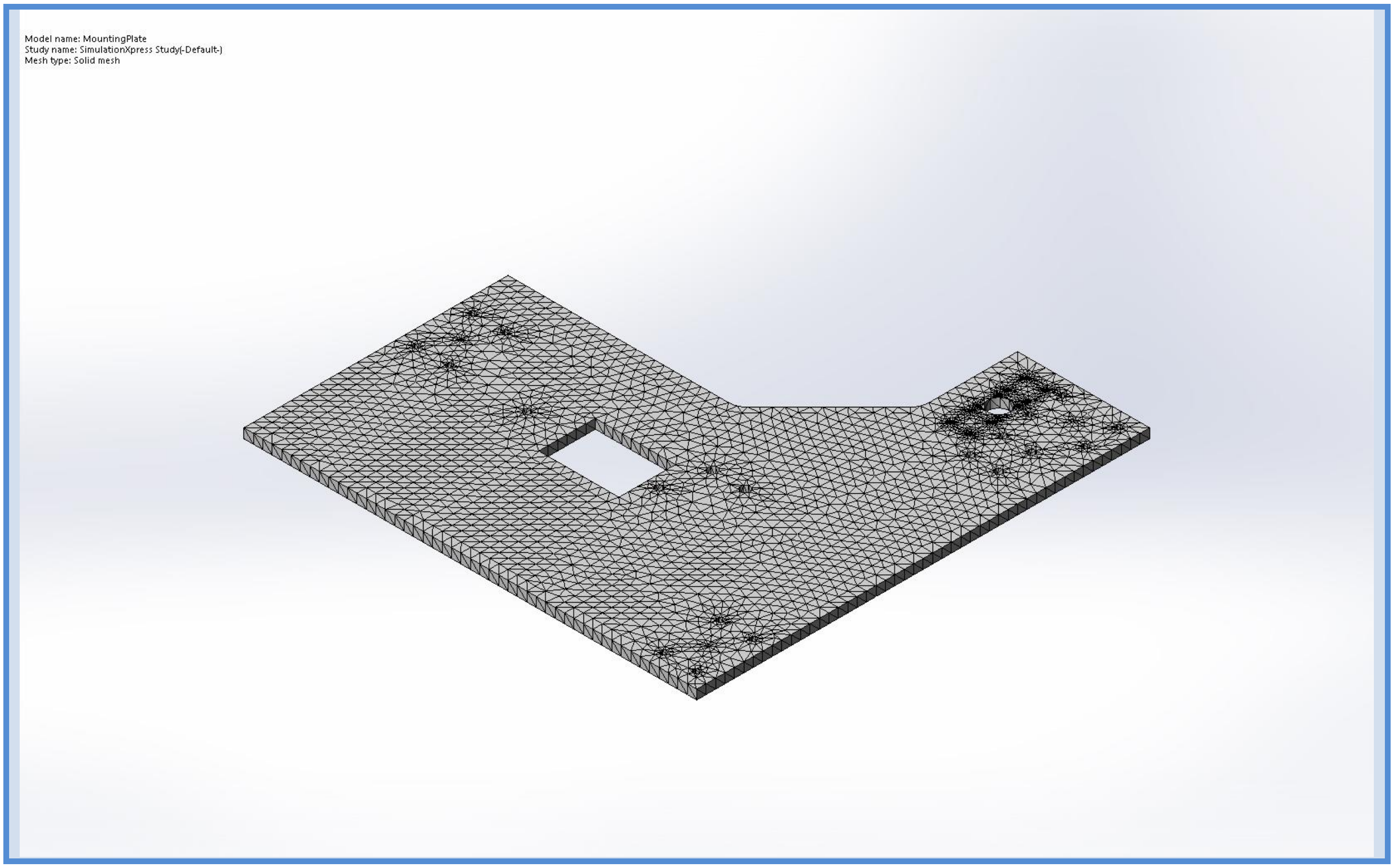
Load name	Load Image	Load Details
Force-2		**Entities:** 2 face(s) **Type:** Apply normal force **Value:** 50 lbf
Force-3		**Entities:** 2 face(s) **Type:** Apply normal force **Value:** 50 lbf
Force-4		**Entities:** 2 face(s) **Type:** Apply normal force **Value:** 50 lbf

Mesh Information

Mesh type	Solid Mesh
Mesher Used:	Standard mesh
Automatic Transition:	Off
Include Mesh Auto Loops:	Off
Jacobian points	4 Points
Element Size	0.50074 in
Tolerance	0.025037 in
Mesh Quality	High

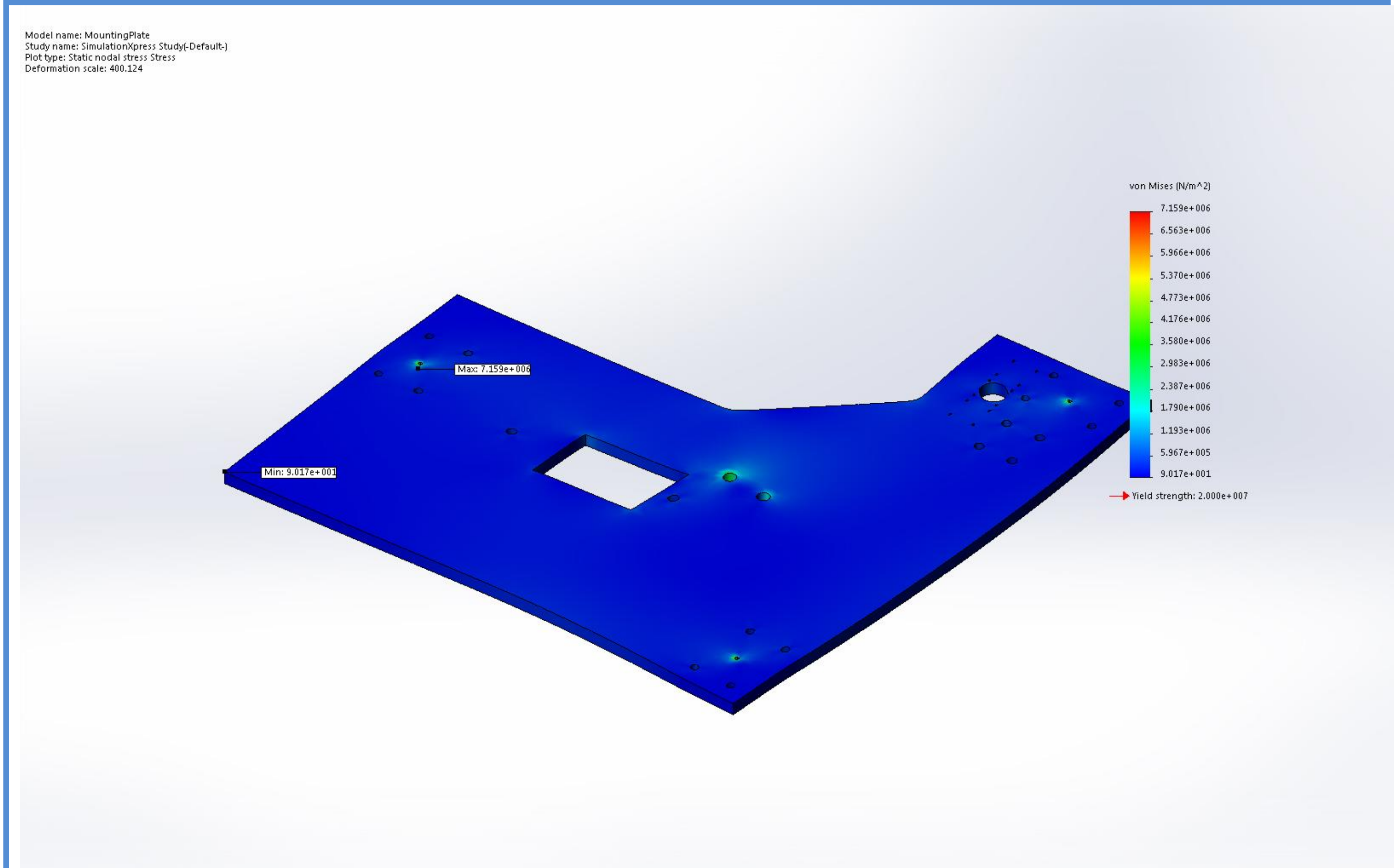
Mesh Information - Details

Total Nodes	46939
Total Elements	27122
Maximum Aspect Ratio	21.047
% of elements with Aspect Ratio < 3	90
% of elements with Aspect Ratio > 10	0.675
% of distorted elements(Jacobian)	0
Time to complete mesh(hh;mm;ss):	00:00:04
Computer name:	DCPC61823


Model name: MountingPlate
Study name: SimulationXpress Study(-Default-)
Mesh type: Solid mesh

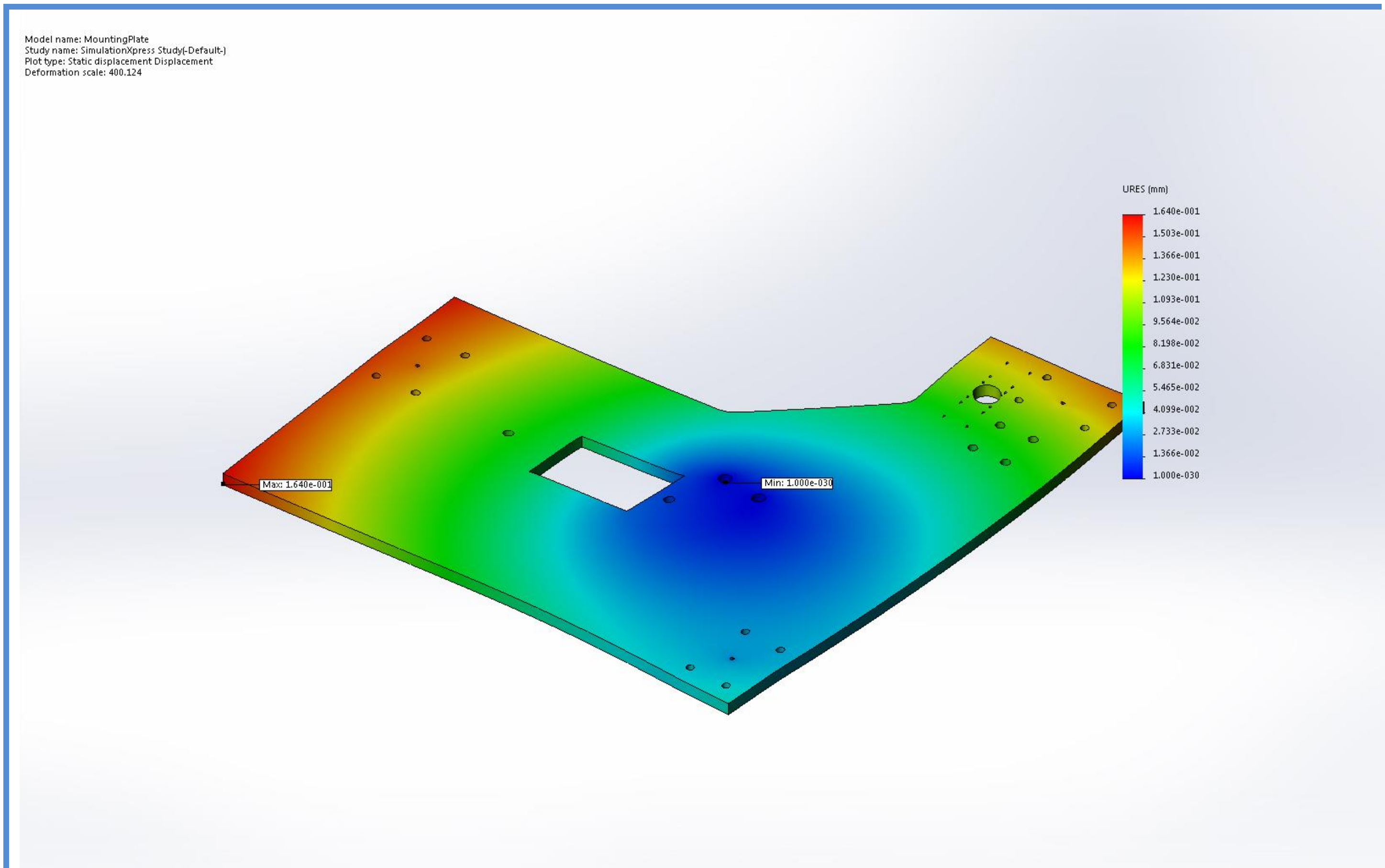
Study Results

Name	Type	Min	Max
Stress	VON: von Mises Stress	90.1707 N/m^2 Node: 548	7.15948e+006 N/m^2 Node: 41804



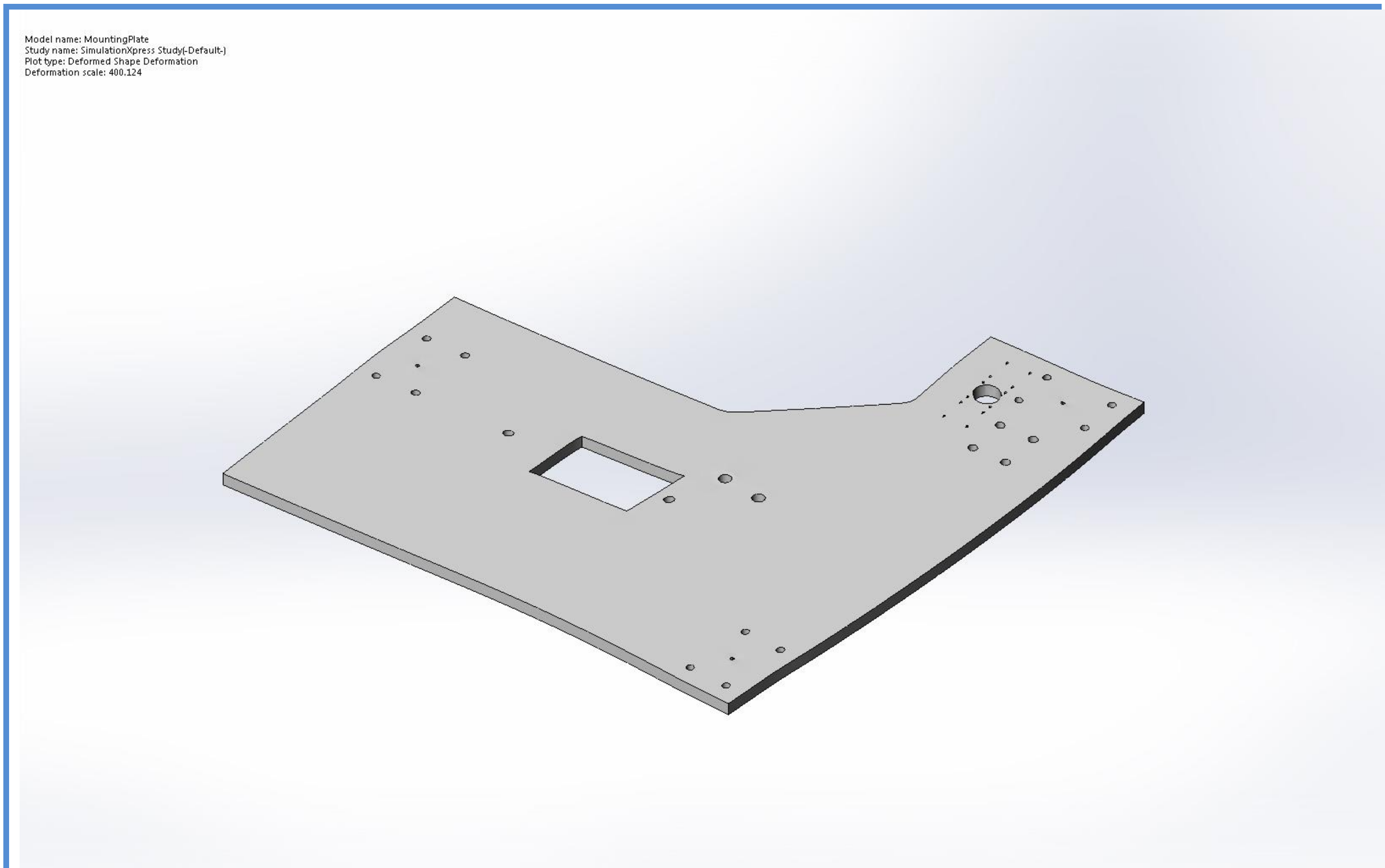
MountingPlate-SimulationXpress Study-Stress-Stress

Name	Type	Min	Max
Displacement	URES: Resultant Displacement	0 mm Node: 231	0.163952 mm Node: 451



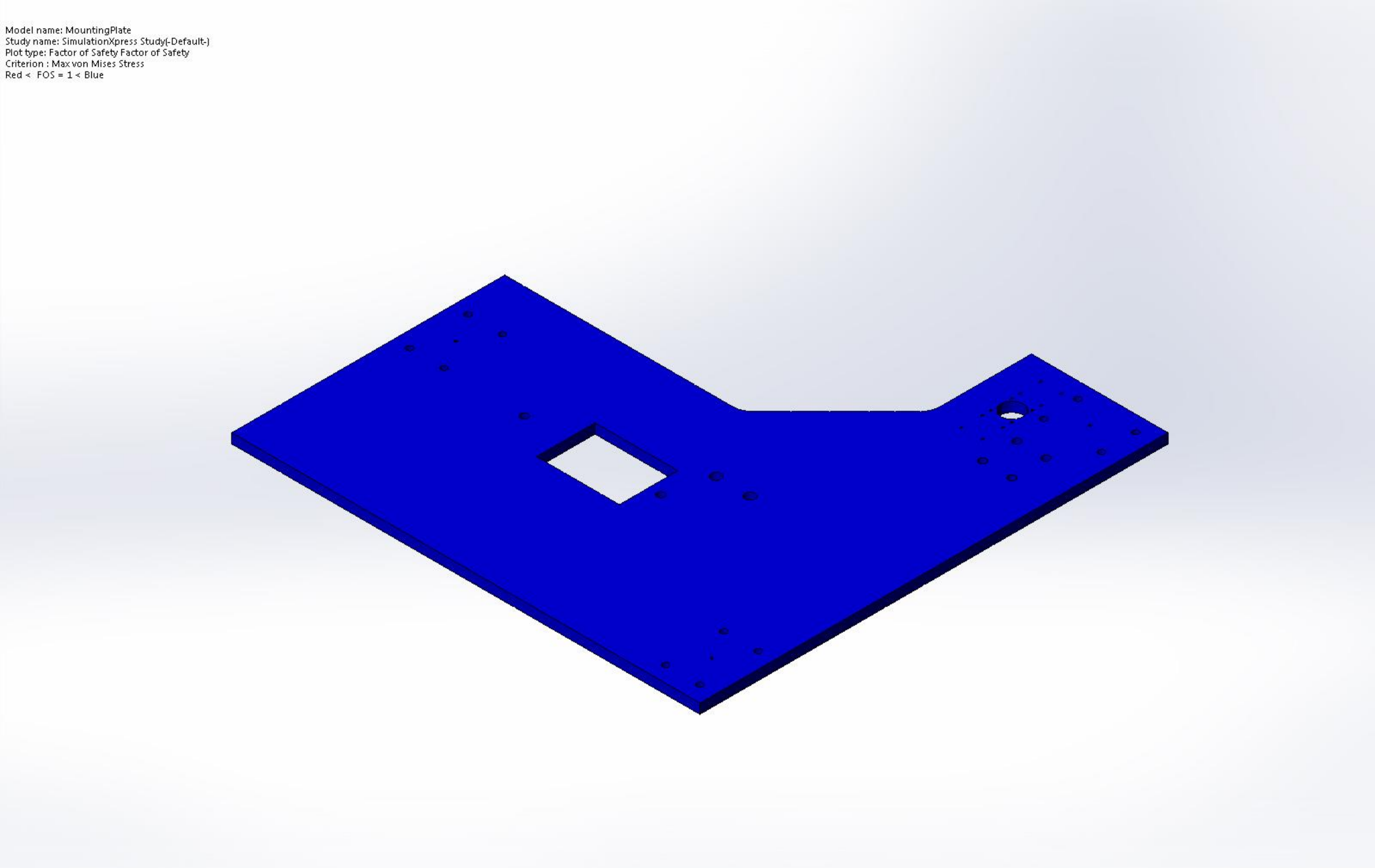
MountingPlate-SimulationXpress Study-Displacement-Displacement

Name	Type
Deformation	Deformed Shape



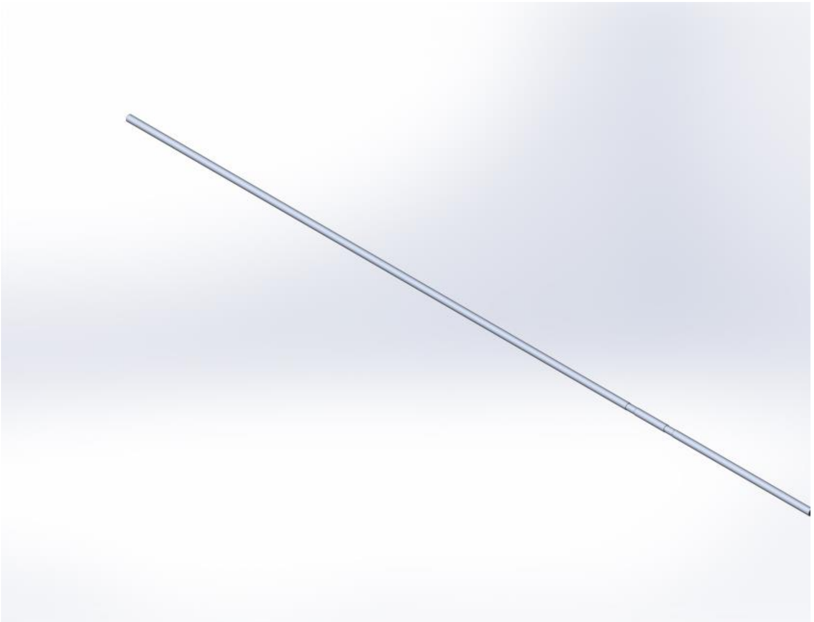
MountingPlate-SimulationXpress Study-Displacement-Deformation

Name	Type	Min	Max
Factor of Safety	Max von Mises Stress	2.7935 Node: 41804	221801 Node: 548



MountingPlate-SimulationXpress Study-Factor of Safety-Factor of Safety

Conclusion



Simulation of SensorArm

Date: Monday, June 08, 2015
Designer: Solidworks
Study name: SimulationXpress Study
Analysis type: Static

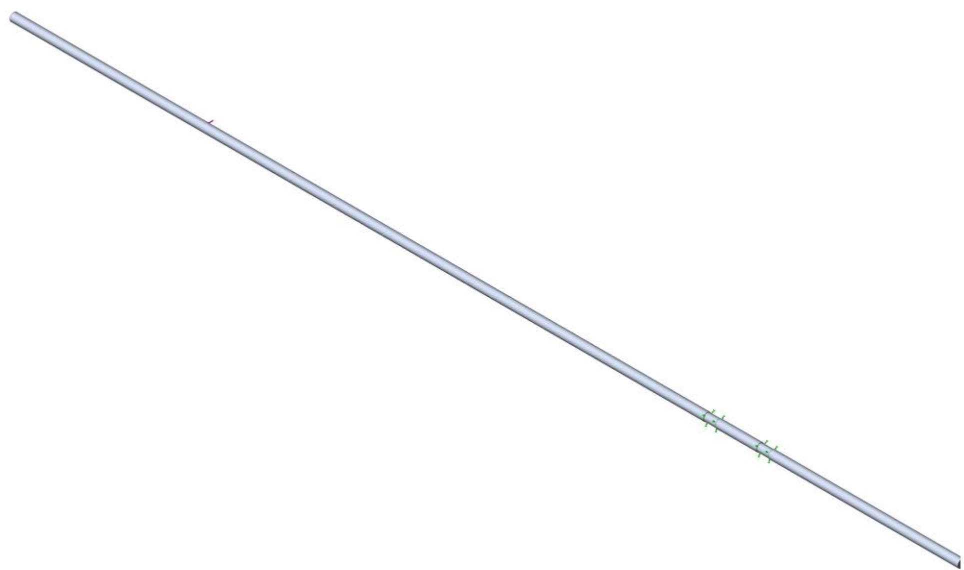
Table of Contents

Description

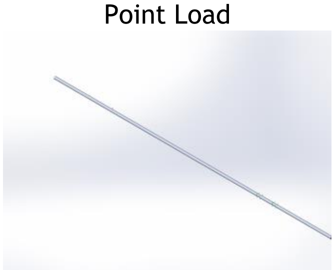
No Data

Assumptions

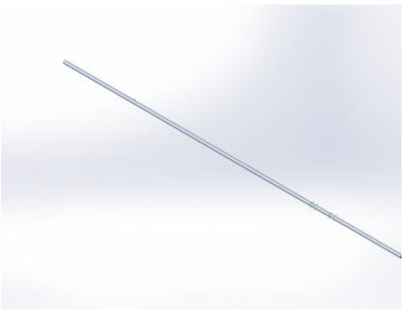
Model Information



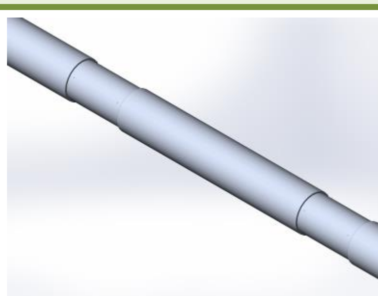
Model name: SensorArm
Current Configuration: Default

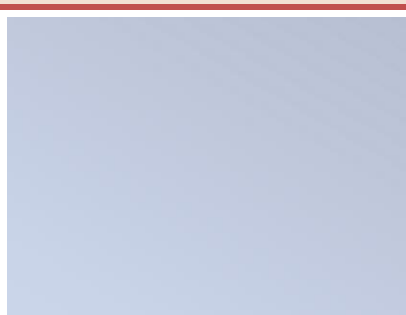
Solid Bodies			
Document Name and Reference	**Treated As**	**Volumetric Properties**	**Document Path/Date Modified**
Point Load 	Solid Body	**Mass:0.0649059 kg** **Volume:2.40392e-005 m^3** **Density:2700 kg/m^3** **Weight:0.636078 N**	**\\samba1\jbaculi\dcengr\Desktop\Undergrad\Senior Design\Sensor Arm Assembly_02\SensorArm.SLDPRT** May 13 13:09:23 2015

Material Properties

Model Reference	Properties	Components
	**Name:** 6061-T6 (SS) **Model type:** Linear Elastic Isotropic **Default failure criterion:** Unknown **Yield strength:** 2.75e+008 N/m^2 **Tensile strength:** 3.1e+008 N/m^2	SolidBody 1(Point Load)(SensorArm)

Loads and Fixtures

Fixture name	Fixture Image	Fixture Details
Fixed-1		**Entities:** 2 face(s) **Type:** Fixed Geometry

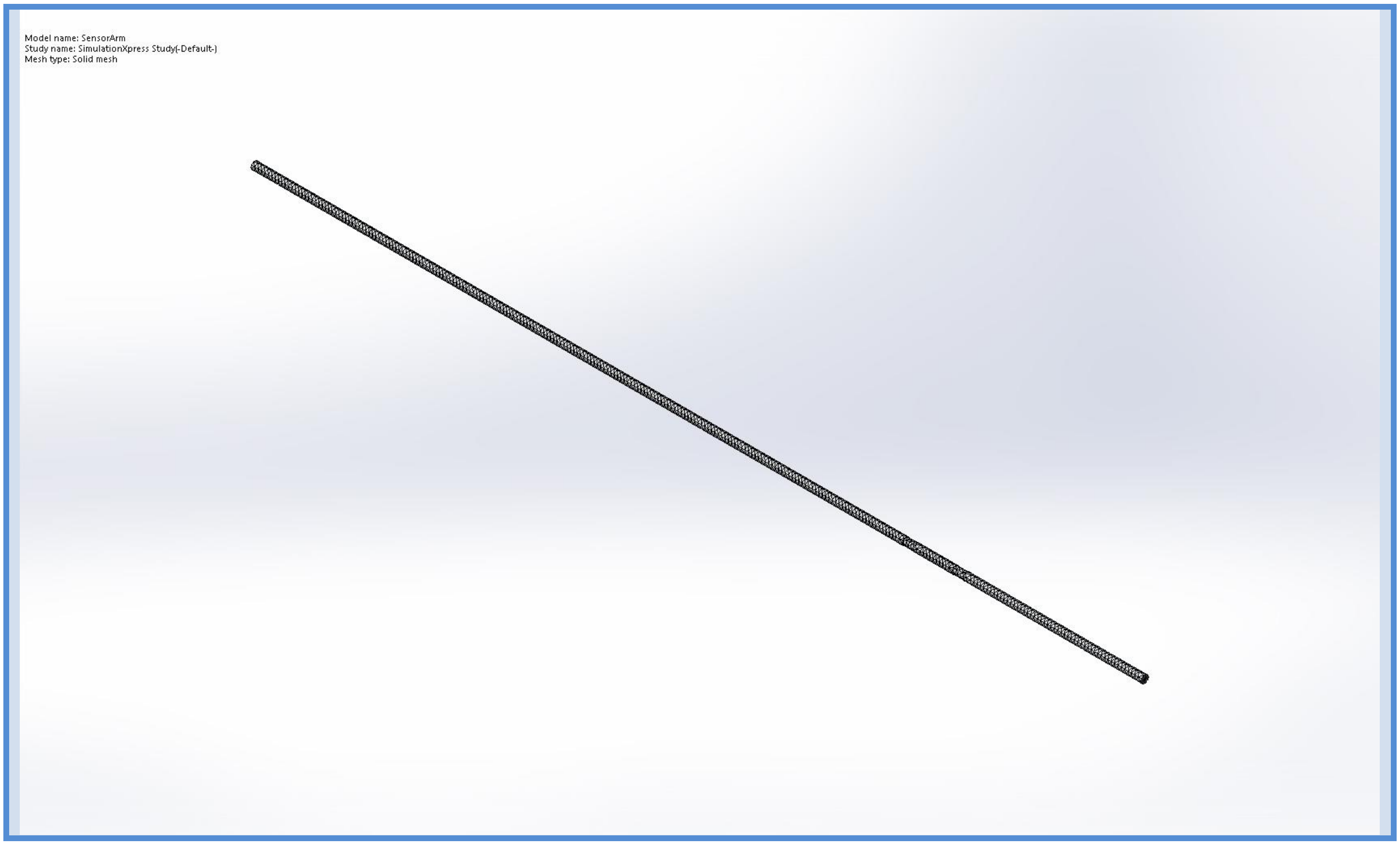
Load name	Load Image	Load Details
Force-1		**Entities:** 1 face(s) **Type:** Apply normal force **Value:** 2 lbf

Mesh Information

Mesh type	Solid Mesh
Mesher Used:	Standard mesh
Automatic Transition:	Off
Include Mesh Auto Loops:	Off
Jacobian points	4 Points
Element Size	0.113616 in
Tolerance	0.00568082 in
Mesh Quality	High

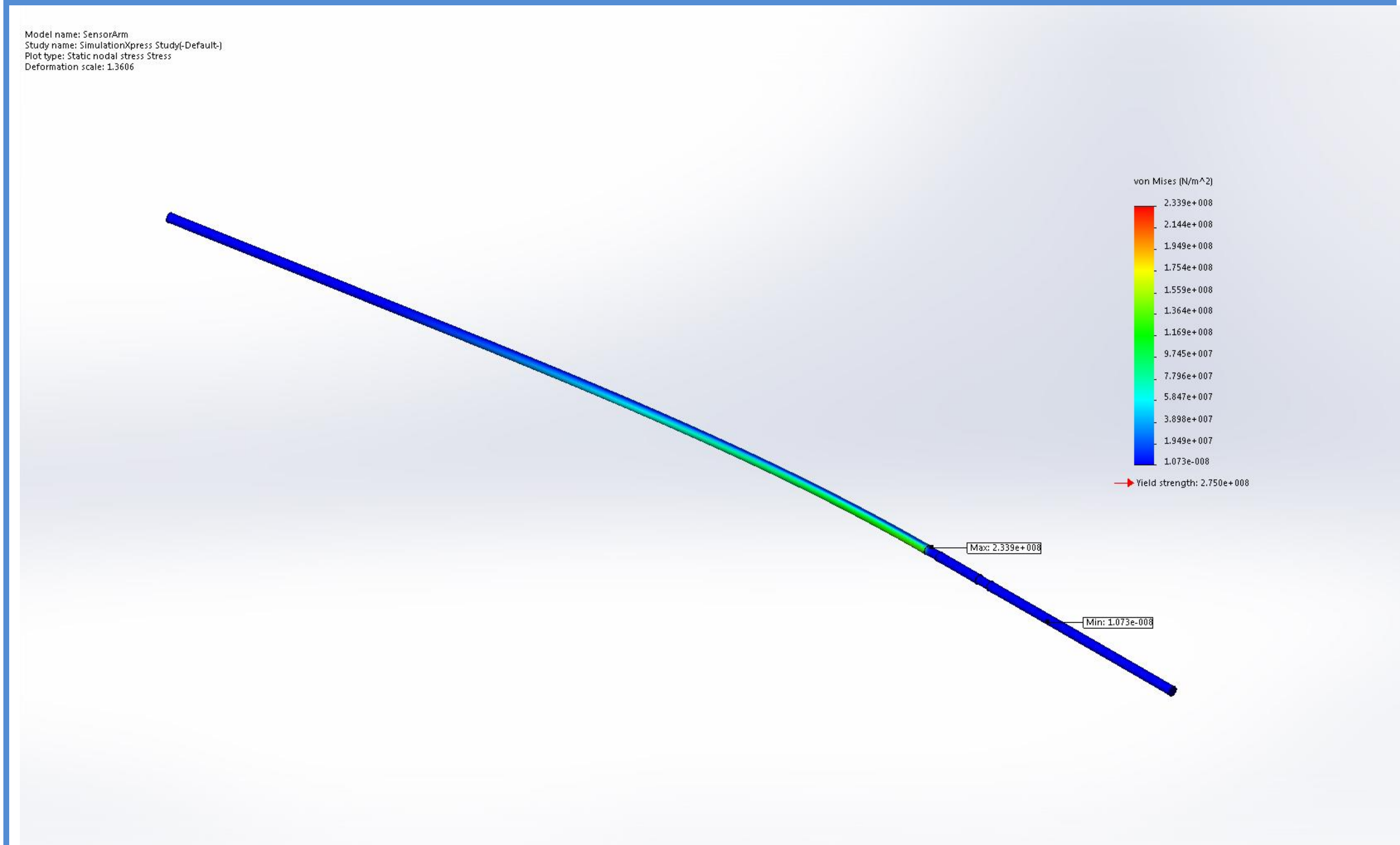
Mesh Information - Details

Total Nodes	11345
Total Elements	5546
Maximum Aspect Ratio	14.12
% of elements with Aspect Ratio < 3	95.6
% of elements with Aspect Ratio > 10	1.42
% of distorted elements(Jacobian)	0
Time to complete mesh(hh;mm;ss):	00:00:01
Computer name:	DCPC60821


Model name: SensorArm
Study name: SimulationXpress Study(-Default-)
Mesh type: Solid mesh

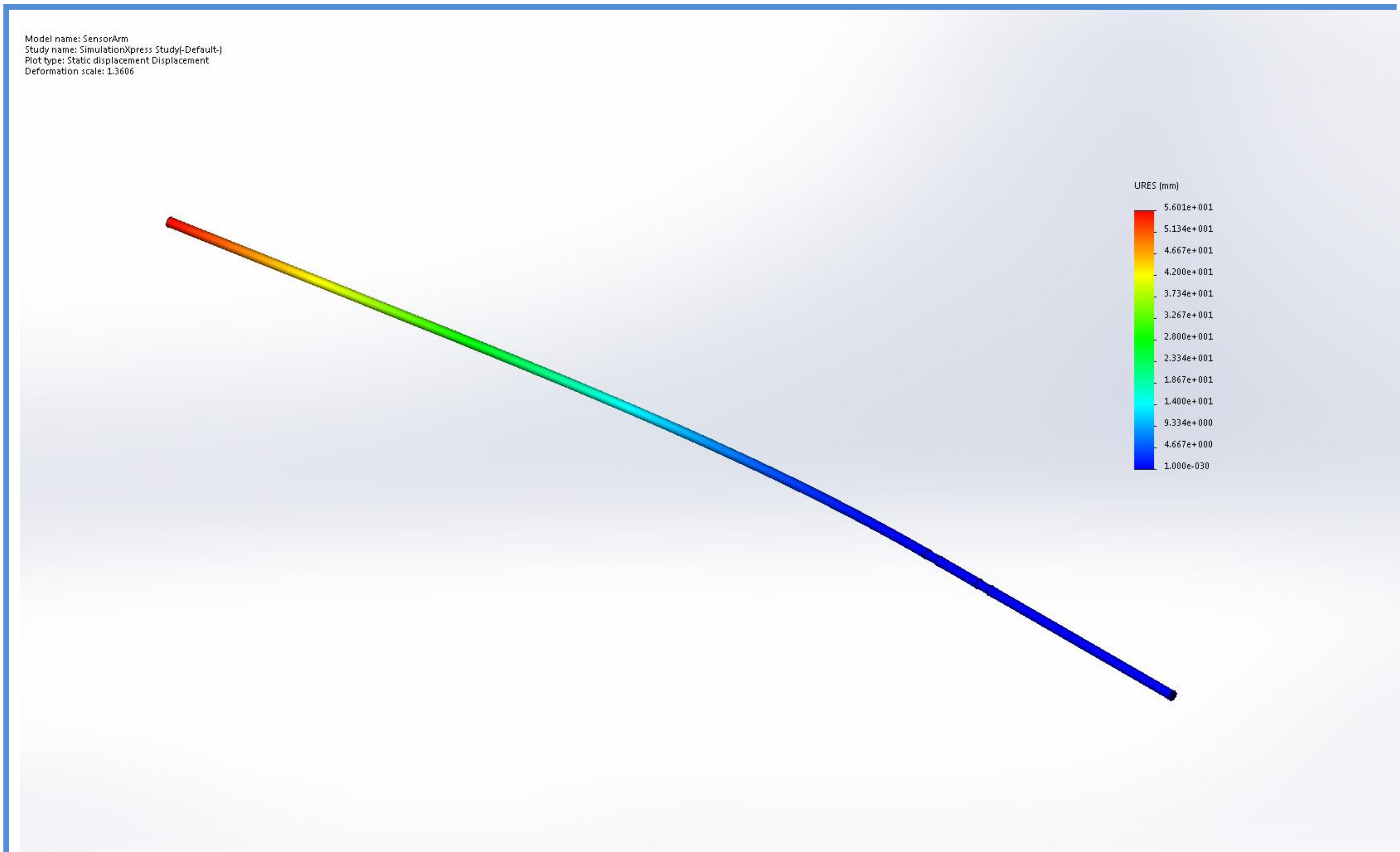
Study Results

Name	Type	Min	Max
Stress	VON: von Mises Stress	1.07299e-008 N/m^2 Node: 2780	2.33871e+008 N/m^2 Node: 11180



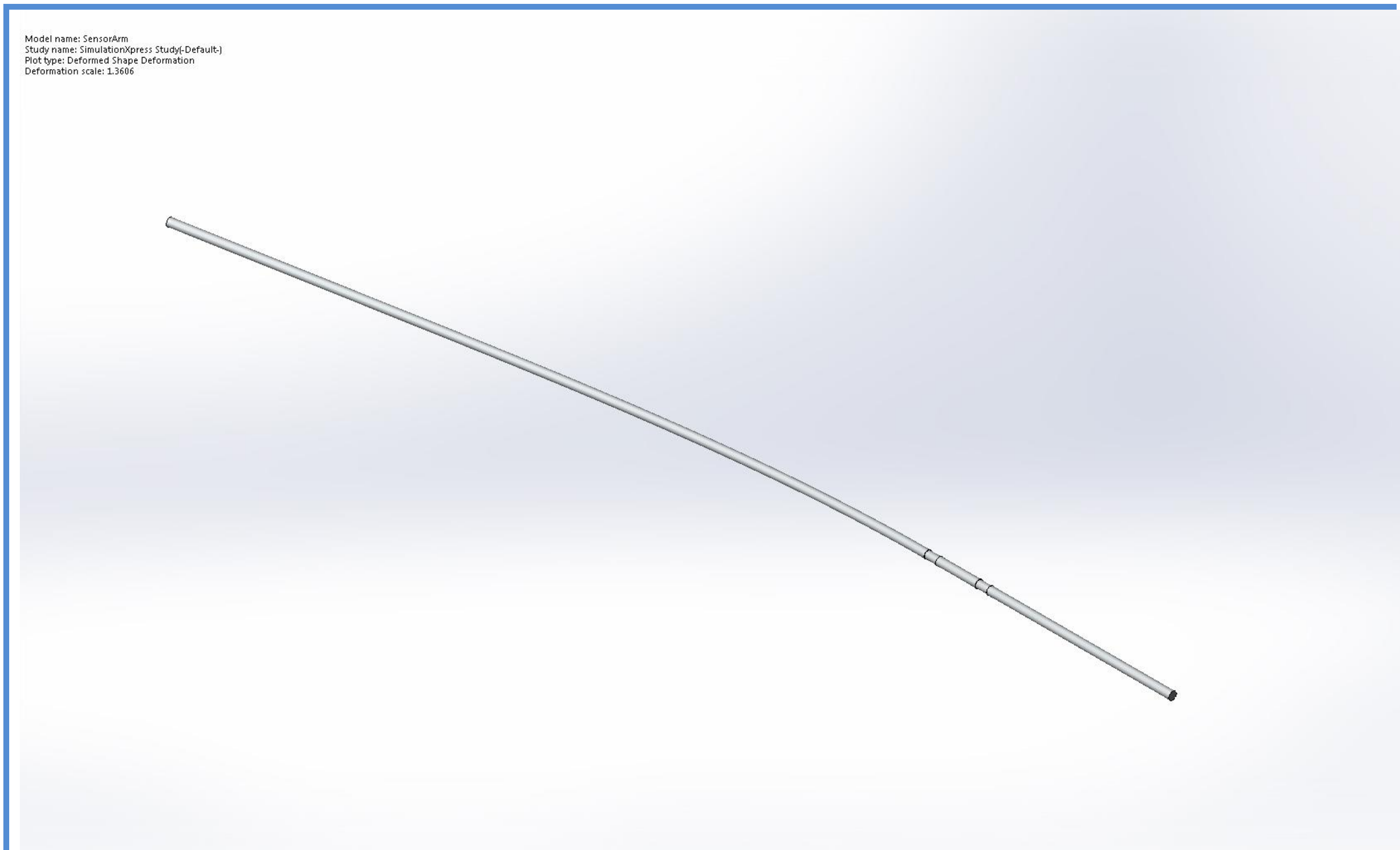
SensorArm-SimulationXpress Study-Stress-Stress

Name	Type	Min	Max
Displacement	URES: Resultant Displacement	0 mm Node: 1	56.0058 mm Node: 9100



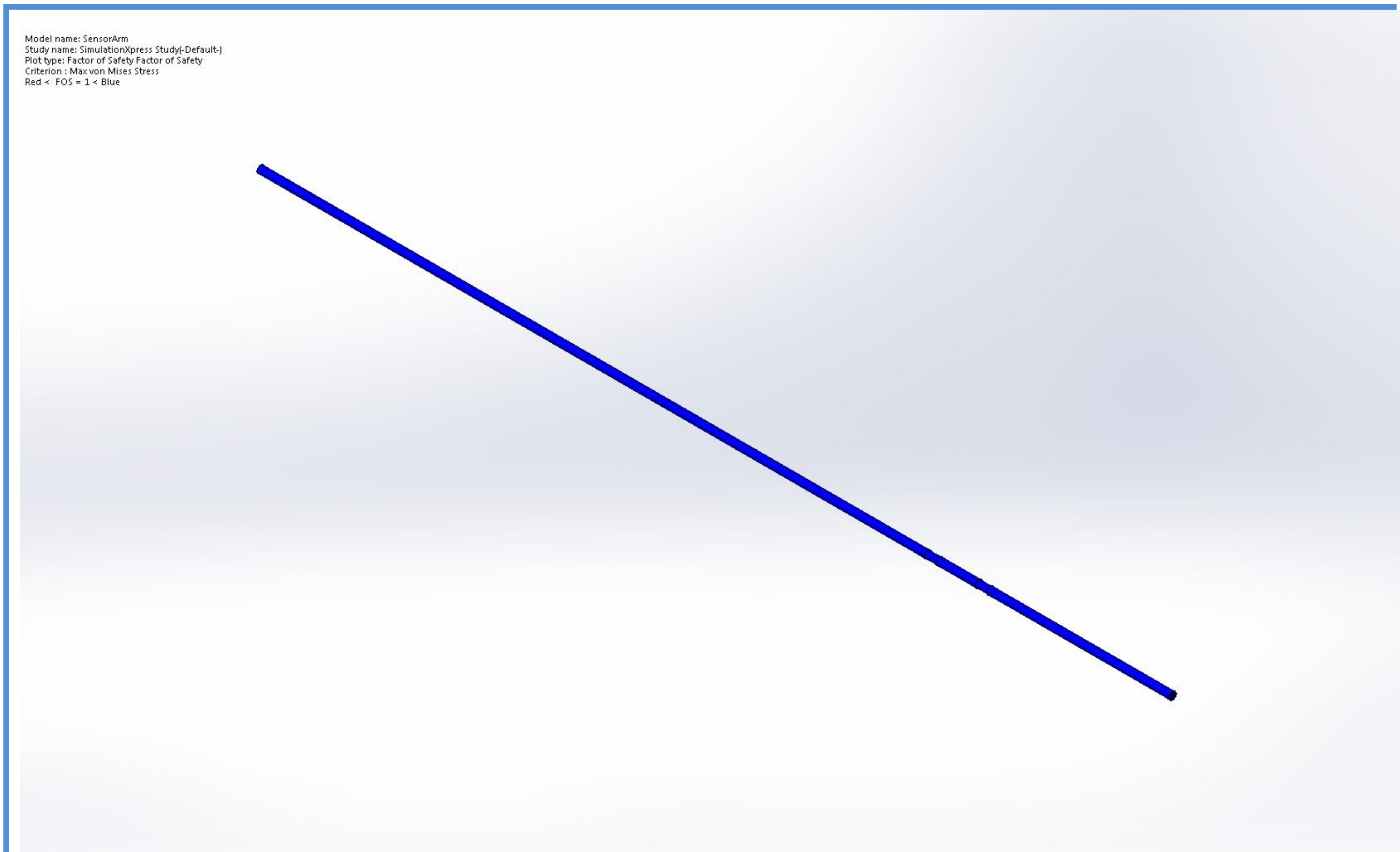
SensorArm-SimulationXpress Study-Displacement-Displacement

Name	Type
Deformation	Deformed Shape



SensorArm-SimulationXpress Study-Displacement-Deformation

Name	Type	Min	Max
Factor of Safety	Max von Mises Stress	1.17586 Node: 11180	1e+016 Node: 1911



SensorArm-SimulationXpress Study-Factor of Safety-Factor of Safety

Conclusion

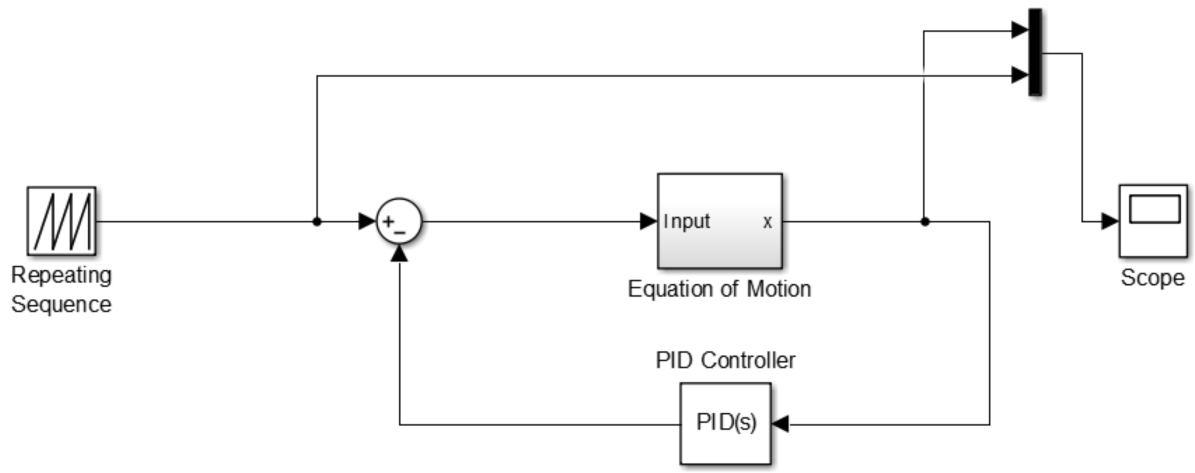


Figure C.1: The top level of the MathWorks Simulink simulation.

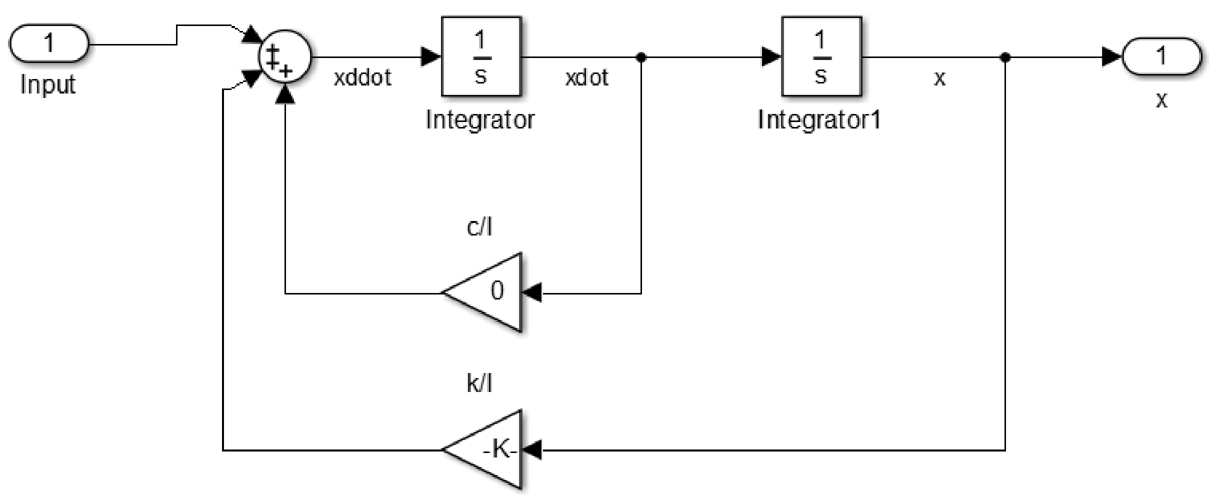
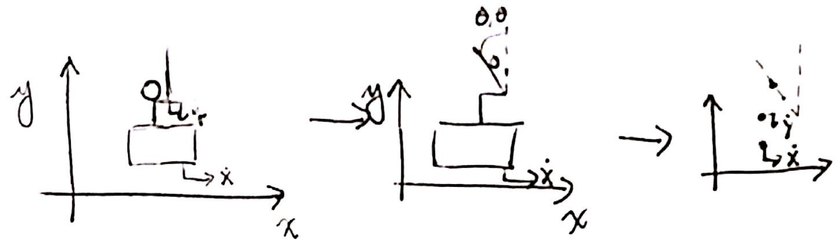


Figure C.2: The equation of motion subsystem of the MathWorks Simulink simulation.



$q_1 = x$

$q_2 = y$

$q_3 = \theta$

$$KE = \frac{1}{2}m_1 v_1^2 + \frac{1}{2}m_2(v_1^2+v_2^2)^2 + \frac{1}{2}m_3(v_1^2+v_2^2+v_3^2)^2$$

$$= \frac{1}{2}m_1\dot{x}^2 + \frac{1}{2}m_2(\dot{x}^2+\dot{y}^2) + \frac{1}{2}m_3\left[(\dot{x} - R\sin\theta)\hat{i} + (-\dot{y} - R\cos\theta)\hat{j}\right]^2$$

$$= \frac{1}{2}m_1\dot{x}^2 + \frac{1}{2}m_2(\dot{x}^2+\dot{y}^2) + \frac{1}{2}m_3\left[(\dot{x}^2 - 2R\dot{x}\sin\theta + R^2\sin^2\theta)\hat{i} + (\dot{y}^2 + 2R\dot{y}\cos\theta + R^2\cos^2\theta)\hat{j}\right]$$

$$PE = \frac{1}{2}k\theta^2$$

$$L = KE - PE$$

$$= \frac{1}{2}(m_1+m_2+m_3)\dot{x}^2 + \frac{1}{2}(m_2+m_3)\dot{y}^2 + \frac{1}{2}m_3\left[(-2R\dot{x}\sin\theta + R^2\sin^2\theta)\hat{i} + (+2R\dot{y}\cos\theta + R^2\cos^2\theta)\hat{j}\right] - \frac{1}{2}k\theta^2$$

NON-LINEAR

$$\frac{\partial L}{\partial q_1} = 0 \qquad \frac{\partial L}{\partial \dot{q}_1} = (m_1+m_2+m_3)\dot{x} + m_3 R\sin\theta$$

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}_1}\right) = (m_1+m_2+m_3)\ddot{x} + \dot{\theta}^2 m_3 R\cos\theta + \ddot{\theta} m_3 R\sin\theta$$

$$\frac{\partial L}{\partial q_2} = 0 \qquad \frac{\partial L}{\partial \dot{q}_2} = (m_2+m_3)\dot{y} + m_3 R\cos\theta$$

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}_2}\right) = (m_2+m_3)\ddot{y} - m_3 R\dot{\theta}^2\sin\theta + \ddot{\theta} m_3 R\cos\theta$$

$$\frac{\partial L}{\partial q_3} = -k\theta \qquad \frac{\partial L}{\partial \dot{q}_3} = -m_3 R\dot{x}\sin\theta + m_3 R\dot{y}\cos\theta$$

$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}_3}\right) = R m_3\left[\ddot{y}\cos\theta - \dot{y}\sin\theta\,\dot{\theta} - \ddot{x}\sin\theta - \dot{x}\dot{\theta}\cos\theta\right]$$

Figure C.3: The dynamical analysis of of AIRWT system in motion.

Appendix D

Electrical Circuit

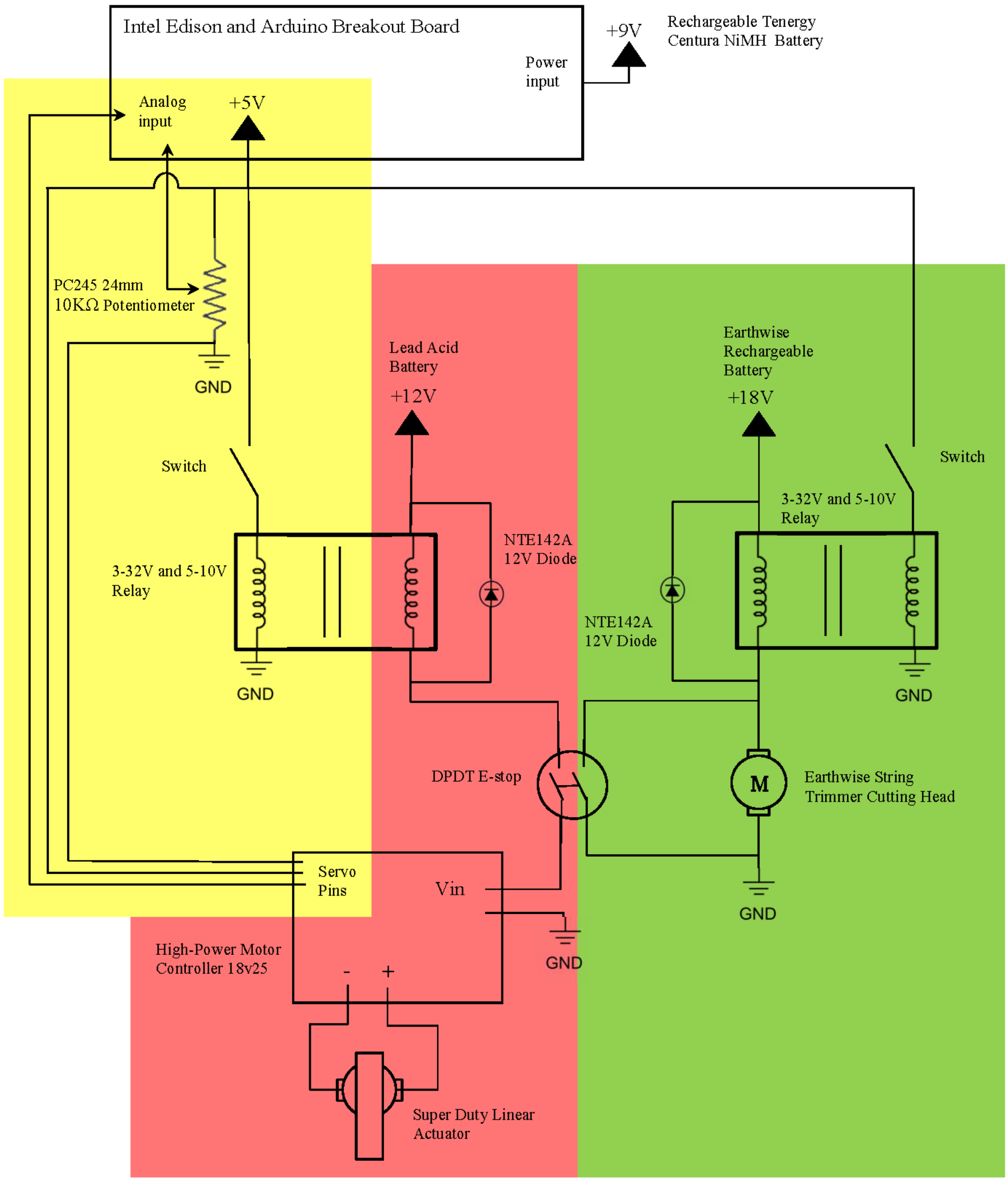


Figure D.1: Circuit of the AIRWT system.

Appendix E

Electrical Components

ServoCity - Motors & Accessories - 12V Linear Actuators - 560 lbs. Thrust Linear Actuator -

search

- Actobotics
- Servos & Accessories
- Motors & Accessories
- Servo Controllers
- Motor Controllers
- Transmitters & Accessories
- Pan/Tilt/Roll & Accessories
- Camera Accessories
- Robots & Accessories
- Channel & Brackets
- Shafting & Tubing
- Hubs, Couplers & Adaptors
- Bearings & Bushings
- Gears
- Sprockets & Chain
- Pulleys & Belts
- Wheels & Tires
- Fasteners & Hardware
- Batteries & Power Supplies
- Wire/Connectors & Access.
- Electronics & Accessories
- Tools
- Web Specials
- Discounts & Promotions
- Contact Us
- Project Center

560 lbs. Thrust Linear Actuator

Shopping Cart

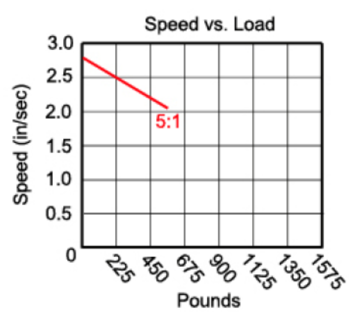
MAXIMUM THRUST 560 lbs. **MAXIMUM SPEED 2.63 Inches per sec.**

Move up to 550 lbs for under $400! **Our super duty linear actuators can be used in place of pneumatics and hydraulics. The super duty linear actuators are driven by high torque brushed DC gearmotors coupled to a ball-screw to create a low friction linear drive. The ball-screw provides efficient linear thrust that can handle loads in both the pushing and pulling orientation. The linear actuators can handle an incredible amount of static load and will hold position even when power is removed. The actuators are equipped with independently adjustable limit switches in the base that will cut power when tripped to prevent over-run. Each actuator has a built-in potentiometer which can be used for positioning feedback if your application requires. The aluminum and steel construction with full metal drive gears ensures tremendous durability and reliability. We offer them in six stroke lengths from 4 inches up to 24 inches. Extension shaft is 1.125" diameter. Mounting holes are 1/2" diameter and bolt up directly to our optional mounting brackets. Note: These systems are extremely powerful and caution must be used during operation.**

Powder coated aluminum base
Stainless steel extension rod
Steel protection tube

Detailed Specifications

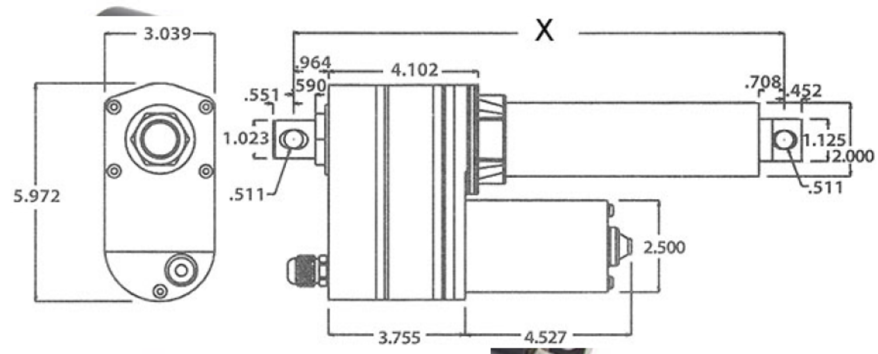
Operating Voltage: 6.0-12 Volts DC
Operating Temperature Range: -25 to + 65°C -13 to + 149°F
Operating Speed (12V): 2.63" second at No load
Operating Speed (12V): 1.85" second at Max load
Dynamic Thrust (12V): 560 lbs. Thrust
Static Load: 3,050 lbs.
Current Drain (12V): 3A operating No load
Motor Type: 3 Pole Ferrite
Potentiometer: l0K
Gear Ratio: 5:1 Ratio
Gear Type: 4 Metal Gears
Connector Wire Length: 12"
Recommended Fuse: 20 amp inline
IP Grade: IP 65-total dust protection, water resistant
Duty cycle: 25% (25% on, 75% off)



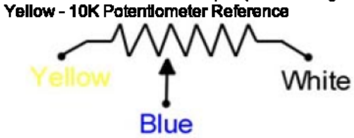
Features:
-Sealed O-ring
-Durable design for even the toughest industrial applications
-Clutch overload protection
-Metal gears
-CE Certified (CD55011)

X = Center to Center		
Stroke	**Retracted**	**Extended**
4"	15.71"	19.73"
6"	17.72"	23.74"
8"	19.72"	27.71"
12"	26.77"	38.78"
18"	32.77"	50.76"
24"	38.76"	62.80"

Figure E.1: ServoCity Linear Actuator Specifications.



Feedback Wiring Schematic:
White - 10K Potentiometer Reference
Blue - 10K Potentiometer Wiper (Position Signal)
Yellow - 10K Potentiometer Reference



DPDT 20A Actuator Switch
Price: **$9.99**
Part: **275-709**
Status: **In-Stock**
Qty: 1 **Add to Cart**

The Digital Manual Speed Controller provides proportional forward and reverse control of your linear actuator. Simply supply 6-16V to the controller and plug in your linear actuator. The speed and direction are controlled by the knob.

To get your actuator up and running, apply 6-12VDC to the positive (red) and negative (black) wires. You do not need to do anything with the potentiometer wires (Blue, Yellow, White). The potentiometer wires are only needed if you are building a system which requires you to know the exact position of the actuator piston. For normal operation, we recommend purchasing the switch above and wiring the switch according to the schematic.

Stroke	Part #	Weight	Price	Status	Qty	Buy
4"	SDA4-263	142.3 oz.	$399.99	In-Stock	1	Add to Cart
6"	SDA6-263	158.9 oz.	$399.99	In-Stock	1	Add to Cart
8"	SDA8-263	172.6 oz.	$399.99	Out of Stock	1	
12"	SDA12-263	186.7 oz.	$399.99	In-Stock	1	Add to Cart
18"	SDA18-263	200.4 oz.	$399.99	In-Stock	1	Add to Cart
24"	SDA24-263	221.8 oz.	$399.99	In-Stock	1	Add to Cart

https://www.servocity.com/html/560_lbs__thrust_linear_actuato.html#.VVwLe47F8qx 2/3

Figure E.2: ServoCity Linear Actuator Specifications.

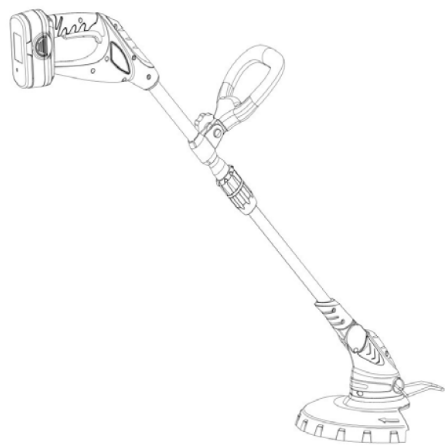
EARTHWISE
The Clean Air Choice

OPERATOR'S MANUAL

CORDLESS 18 VOLT STRING TRIMMER

This product is covered by U.S. patents and other international patents

CST00012



Your string trimmer has been engineered and manufactured to our high standard for dependability, ease of operation, and operator safety. Properly cared for, it will give you years of rugged, trouble-free performance.

WARNING: To reduce the risk of injury, the user must read and understand the operator's manual before using this product.

BATTERY MUST BE CHARGED BEFORE FIRST USE.

Thank you for your purchase.

DO NOT RETURN THIS PRODUT TO THE STORE. OPERATING, ASSEMBLY, PARTS, SERVICE QUESTIONS? CALL 1-800-313-5111 BETWEEN 7:30AM—4:30PM EST FOR ASSISTANCE.

SAVE THIS MANUAL FOR FUTURE REFERENCE

Figure E.3: Earthwise Cordless String Trimmer Specifications.

FEAUTRES

PRODUCT SPECIFICATIONS

CST00012

Input	18 V, DC only
Battery	18 V, 1.7Ah Ni-Cd
Speed	7800 RPM
Cutting Width	12 in.
Weight	6.28 lb.

- .065 Single Line -Semi Automatic Feed - Edging Function - 3 Position Adjustable Head

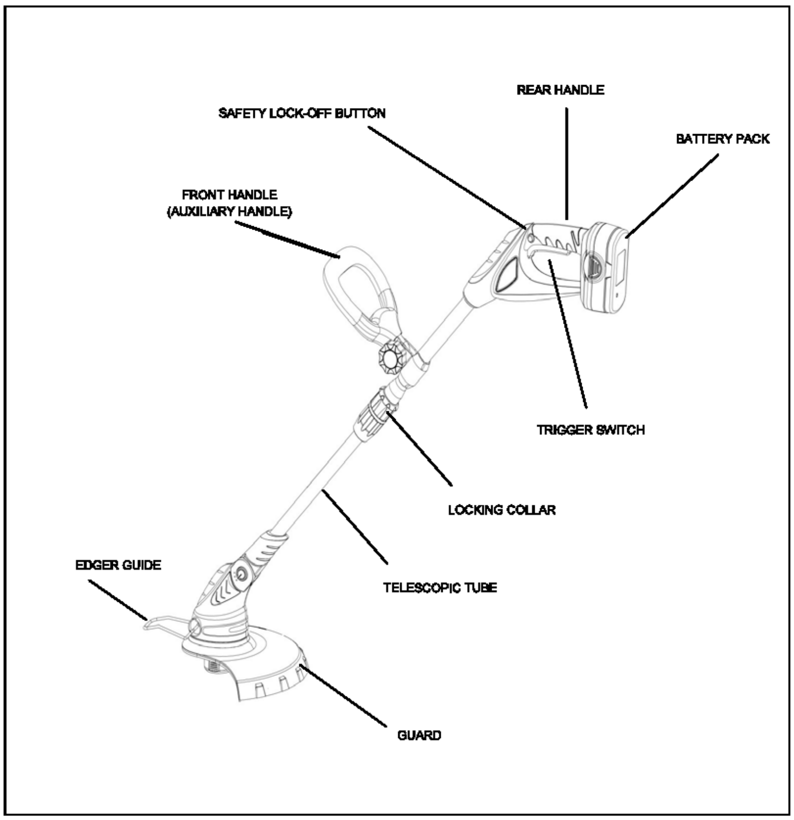


Figure E.4: Earthwise Cordless String Trimmer Specifications.

Product Brief
Intel® Edison

Intel® Edison Development Platform

Introduction

The Intel® Edison development platform is designed to lower the barriers to entry for a range of inventors, entrepreneurs, and consumer product designers to rapidly prototype and produce "Internet of Things" (IoT) and wearable computing products.

Intel® Edison Board for Arduino*

Supports Arduino Sketch, Linux, Wi-Fi, and Bluetooth.

Board I/O: Compatible with Arduino Uno (except 4 PWM instead of 6 PWM):

- 20 digital input/output pins, including 4 pins as PWM outputs.
- 6 analog inputs.
- 1 UART (Rx/Tx).
- 1 I²C.
- 1 ICSP 6-pin header (SPI).
- Micro USB device connector OR (via mechanical switch) dedicated standard size USB host Type-A connector.
- Micro USB device (connected to UART).
- SD card connector.
- DC power jack (7 to15 VDC input).

Intel® Edison Breakout Board

Slightly larger than the Intel® Edison module, the Intel® Edison Breakout Board has a minimal set of features:

- Exposes native 1.8 V I/O of the Edison module.
- 0.1 inch grid I/O array of through-hole solder points.
- USB OTG with USB Micro Type-AB connector.
- USB OTG power switch.
- Battery charger.
- USB to device UART bridge with USB micro Type-B connector.
- DC power supply jack (7 to 15 VDC input).

Intel® IoT Analytics Platform

- Provides seamless Device-to-Device and Device-to-Cloud communication.
- Ability to run rules on your data stream that trigger alerts based on advanced analytics.
- Foundational tools for collecting, storing, and processing data in the cloud.
- Free for limited and noncommercial use.

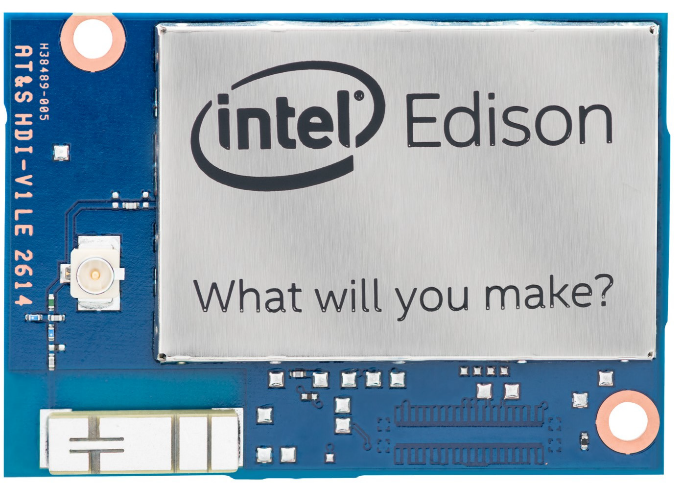
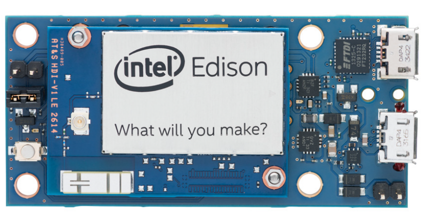


Figure E.5: Intel Edison Development Platform Specifications.

Intel® Edison Development Platform

PHYSICAL	
Form factor	Board with 70-pin connector
Dimensions	35.5 × 25.0 × 3.9 mm (1.4 × 1.0 × 0.15 inches) max
C/M/F	Blue PCB with shields / No enclosure
Connector	Hirose DF40 Series (1.5, 2.0, or 3.0 mm stack height)
Operating temperature	32 to 104°F (0 to 40°C)
EXTERNAL INTERFACES	
Total of 40 GPIOs, which can be configured as:	
SD card	1 interface
UART	2 controllers (1 full flow control, 1 Rx/Tx)
I2C	2 controllers
SPI	1 controller with 2 chip selects
I2S	1 controller
GPIO	Additional 12 (with 4 capable of PWM)
USB 2.0	1 OTG controller
Clock output	32 kHz, 19.2 MHz
MAJOR EDISON COMPONENTS	
SoC	22 nm Intel® SoC that includes a dual-core, dual-threaded Intel® Atom™ CPU at 500 MHz and a 32-bit Intel® Quark™ microcontroller at 100 MHz
RAM	1 GB LPDDR3 POP memory (2 channel 32bits @ 800MT/sec)
Flash storage	4 GB eMMC (v4.51 spec)
WiFi	Broadcom* 43340 802.11 a/b/g/n; Dual-band (2.4 and 5 GHz) Onboard antenna
Bluetooth	Bluetooth 4.0
POWER	
Input	3.3 to 4.5 V
Output	100 ma @3.3 V and 100 ma @ 1.8 V
Power	Standby (No radios): 13 mW Standby (Bluetooth 4.0): 21.5 mW (BTLE in Q4-14) Standby (Wi-Fi): 35 mW
FIRMWARE + SOFTWARE	
CPU OS	Yocto Linux* v1.6
Development environments	Arduino* IDE Eclipse supporting: C, C++, and Python Intel XDK supporting: Node.JS and HTML5
MCU OS	RTOS
Development environments	MCU SDK and IDE



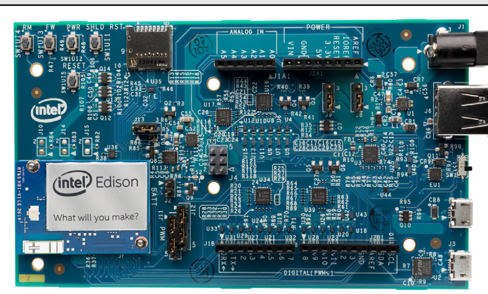
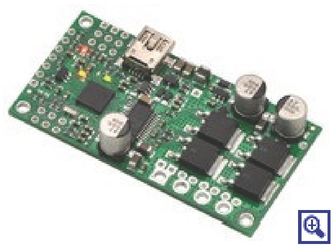


Figure E.6: Intel Edison Development Platform Specifications.

Pololu Simple High-Power Motor Controller 18v25



Pololu item #: 1381 **32** in stock

Price break	Unit price (US$)
1	**54.95**
10	49.46

Quantity: 1 Add to cart
backorders allowed Add to wish list

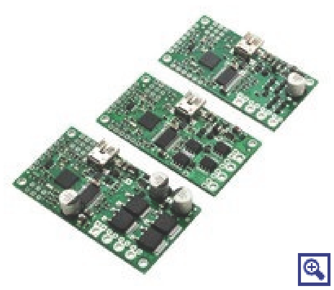
The Pololu Simple High-Power Motor Controller makes basic control of brushed DC motors easy, with our free Simple Motor Control Center software enabling quick configuration over USB. The controller supports four interface modes: USB, TTL serial, analog voltage, and hobby radio control (RC). This version operates from **5.5 to 30 V** and is efficient enough to deliver a continuous **25 A** without a heat sink. It ships with the power capacitor and connectors included but not soldered in, allowing for custom installations.

Select options: 25 A ▼ partial kit? Y ▼ Go ▸

.

Description **Specs (11)** **Pictures (26)** **Resources (7)** **FAQs (1)** On the blog (0)

Overview



Simple Motor Controllers.

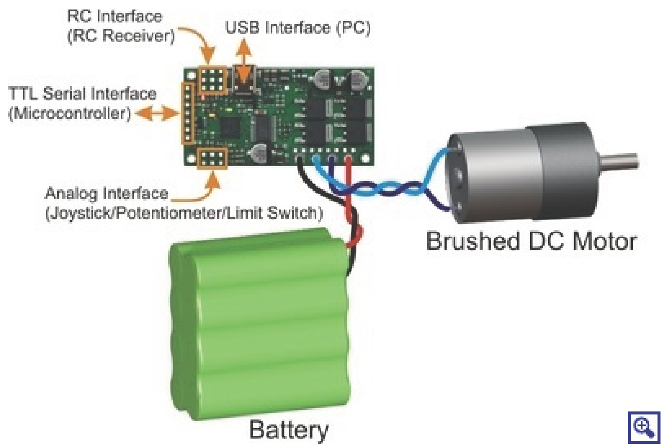
The Pololu Simple Motor Controllers are versatile, general-purpose motor controllers for brushed, DC motors. A wide operating range of up to 5.5–40V and the ability to deliver up to several hundred Watts in a small form factor make these controllers suitable for many motor control applications. With a variety of supported interfaces—USB for direct connection to a computer, TTL serial for use with embedded systems, RC hobby servo pulses for use as an RC-controlled electronic speed control (ESC), and analog voltages for use with a potentiometer or analog joystick—and a wide array of configurable settings, these motor controllers make it easy to add basic control of brushed DC motors to a variety of projects. Although this motor controller has many more features than competing products, a free configuration utility (for Windows 8, 7, Vista, Windows XP, and Linux) simplifies initial setup of the device and allows for in-system testing and monitoring of the controller via USB.

> For 24 V applications, we recommend the 24v12 or 24v23 versions. We strongly recommend against using the 18v7, 18v15, or 18v25 with 24 V batteries, which can significantly exceed 24 V when fully charged and are dangerously close to the maximum voltage limits of these lower-voltage controllers.

Key Features

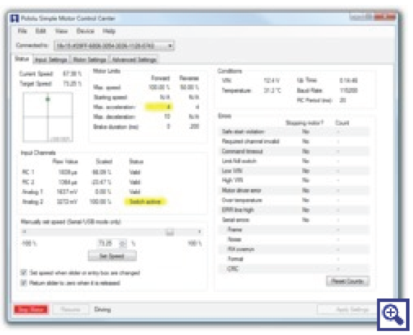
Figure E.7: Pololu Simple High-Power Motor Controller 18v25.

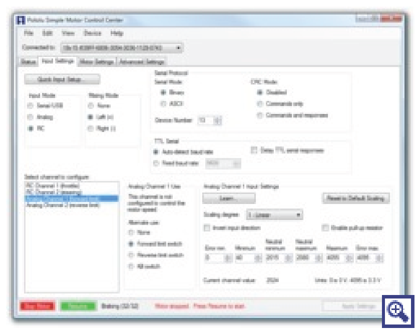
- Simple bidirectional control of one DC brush motor.
- 5.5 V to 30 V (18v7, 18v15, and 18v25) or 40 V (24v12 and 24v23) operating supply range.
- 7 A to 25 A maximum continuous current output without a heat sink, depending on controller model
- Four communication or control options:
  1. USB interface for direct connection to a PC.
  2. Logic-level (TTL) serial interface for direct connection to microcontrollers or other embedded controllers.
  3. Hobby radio control (RC) pulse width interface for direct connection to an RC receiver or **RC servo controller**.
  4. 0–3.3 V analog voltage interface for direct connection to potentiometers and analog joysticks.



Simple High-Power Motor Controller 18v25 or 24v23 simplified connection diagram.

- Simple configuration and calibration over USB with free configuration program (Windows 8, 7, Vista, Windows XP, and Linux compatible).





> **Note:** A **USB A to mini-B cable** (not included) is required to connect this controller to a computer.

Additional Features

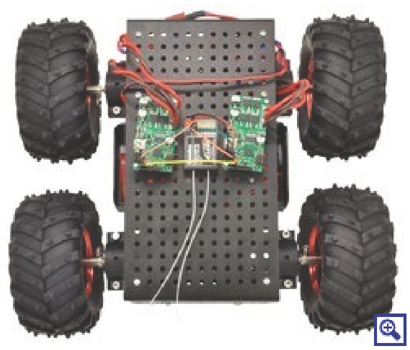
- Comprehensive **user's guide** with plenty of connection diagrams and sample code.
- Adjustable maximum acceleration and deceleration to limit electrical and mechanical stress on the system.
- Adjustable starting speed, maximum speed, and amount of braking when speed is zero.
- Optional safety controls to avoid unexpectedly powering the motor.
- Input calibration (learning) and adjustable scaling degree for analog and RC signals.
- Under-voltage shutoff with hysteresis for use with batteries vulnerable to over-discharging (e.g. LiPo cells).
- Adjustable over-temperature threshold and response.

Figure E.8: Pololu Simple High-Power Motor Controller 18v25.

- Adjustable PWM frequency from 1 kHz to 22 kHz (maximum frequency is ultrasonic, eliminating switching-induced audible motor shaft vibration).
- Error LED linked to a digital ERR output, and connecting the error outputs of multiple controllers together optionally causes all connected controllers to shut down when any one of them experiences an error.
- Field-upgradeable firmware.

- **USB/Serial features:**
  - Controllable from a computer with native USB, via serial commands sent to the device's virtual serial (COM) port, or via TTL serial through the device's RX/TX pins.
  - Example code in C#, Visual Basic .NET, and Visual C++ is available in the **Pololu USB Software Development Kit**
  - Optional CRC error detection to eliminate communication errors caused by noise or software faults.
  - Optional command timeout (shut off motors if communication ceases).
  - Supports automatic baud rate detection from 1200 bps to 500 kbps, or can be configured to run at a fixed baud rate.
  - Supports standard compact and Pololu protocols as well as the Scott Edwards Mini SSC protocol and an ASCII protocol for simple serial control from a terminal program.
  - Optional serial response delay for communicating with half-duplex controllers such as the Basic Stamp.
  - Controllers can be easily chained together and to other Pololu serial motor and servo controllers to control hundreds of motors using a single serial line.

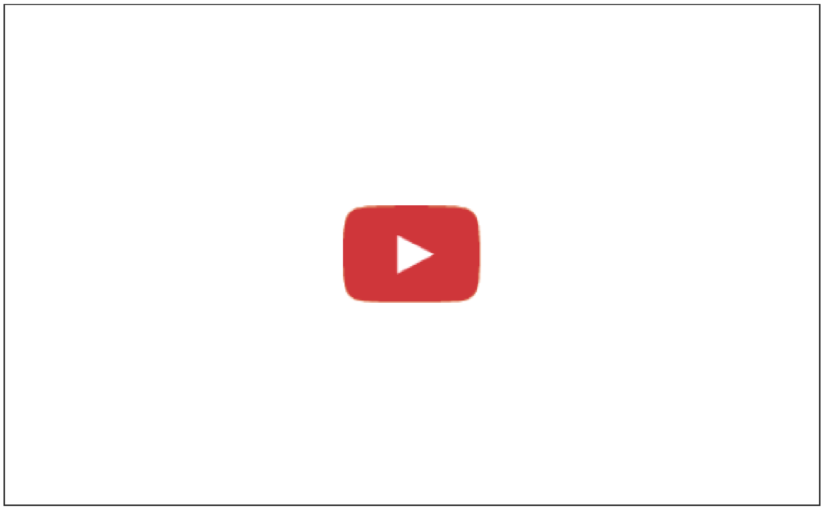
- **RC features:**
  - 1/4 μs pulse measurement resolution.
  - Works with RC pulse frequencies from 10 to 333 Hz.
  - Configurable parameters for determining what constitutes an acceptable RC signal.
  - Two RC channels allow for single-stick (mixed) motor control, making it easy to use two simple motor controllers in tandem on an RC-controlled differential-drive robot (you might find our **RC servo Y splitter cables** useful for connecting two SMCs to a single RC receiver).
  - RC channels can be used in any mode as limit or kill switches (e.g. use an RC receiver to trigger a kill switch on your autonomous robot).
  - Battery elimination circuit (BEC) jumper can power the RC receiver with 5 V or 3.3 V.



Two Pololu Simple Motor Controllers enable mixed RC-control of Dagu Wild Thumper 4WD all-terrain chassis.

- **Analog features:**
  - 0.8 mV (12-bit) measurement resolution.
  - Works with 0 to 3.3 V inputs.
  - Optional potentiometer/joystick disconnect detection.
  - Two analog channels allow for single-stick (mixed) motor control, making it easy to use two simple motor controllers in tandem on a joystick-controlled differential-drive robot.
  - Analog channels can be used in any mode as limit or kill switches.

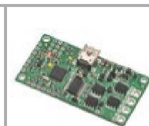
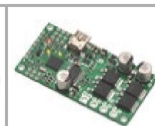
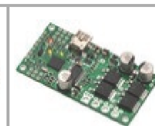
Figure E.9: Pololu Simple High-Power Motor Controller 18v25.



This video demonstrates the versatility of the Simple Motor Controller by showing how it can be controlled directly from the analog output of a Sharp analog distance sensor—there is no intermediate control board and no programming involved. For more information on this example, including the SMC settings file and a list of parts used, see our **blog post about the demo**.

Simple Motor Controller Comparison Table

The Simple Motor Controllers are available in several input voltage ranges and output current ranges:

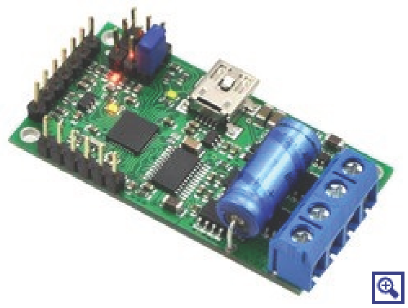
	 18v7	 18v15	 24v12	 18v25	 24v23
Absolute max voltage:	30 V	30 V	40 V	30 V	40 V
Recommended max voltage[(1)]:	24 V	24 V	34 V	24 V	34 V
Max continuous current w/o heat sink:	7 A	15 A	12 A	25 A	23 A
Width:	1.1" (2.8 cm)	1.1" (2.8 cm)	1.1" (2.8 cm)	1.2" (3.1 cm)	1.2" (3.1 cm)
Length:	2.1" (5.3 cm)	2.1" (5.3 cm)	2.1" (5.3 cm)	2.3" (5.8 cm)	2.3" (5.8 cm)
Weight[(2)]:	7 g	7 g	7 g	12 g	12 g
Available with connectors installed?	Yes	Yes	Yes	No	No

[1] We do not recommend using the 18v7, 18v15, or 18v25 versions with 24 V batteries, which can significantly exceed 24 V when fully charged. The 24v12 and 24v23 are the much more appropriate controller for 24 V applications.

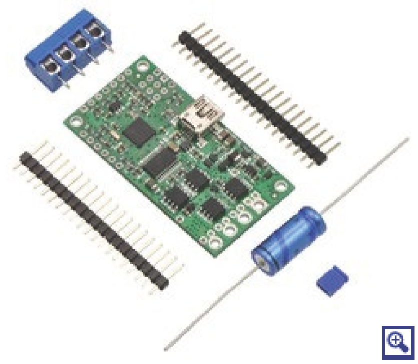
[2] This is the weight of the board without header pins, terminal blocks, or through-hole power capacitor.

Included Hardware

Figure E.10: Pololu Simple High-Power Motor Controller 18v25.



Simple High-Power Motor Controller 18v15 or 24v12, fully assembled.



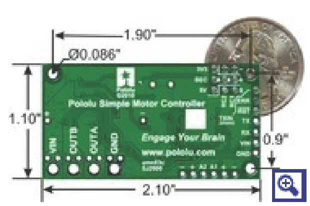
Simple High-Power Motor Controller 18v15 or 24v12, partial kit with included hardware.

Most Simple Motor Controllers are available "fully assembled", with the power capacitor and connectors pre-installed, or with these components included but not soldered in. For example, a fully assembled 18v15 ships as shown in the left picture above, and an 18v15 with included hardware ships as shown in the right picture above (the included hardware consists of a power capacitor, a **40×1 straight 0.1" male header strip**, a **5mm-pitch 4-pin terminal block**, and a **blue shorting block**).

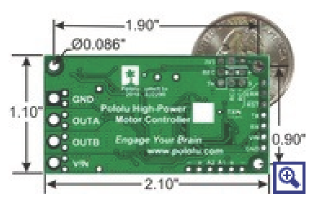
The connector-free version allows flexibility in choice of connectors and placement of the power capacitor (e.g. on the other side of the board) to accommodate compact installations or to make room for a heat sink.

> **Note:** The power capacitor has a **significant** effect on performance; the included capacitor is the minimum size recommended, and bigger ones can be added if there is space. A bigger capacitor might be required if the power supply is poor or far (more than about a foot) from the controller.

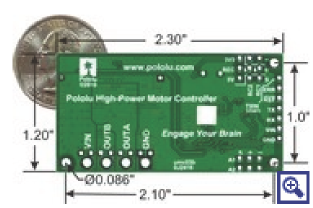
The included terminal blocks are only rated for 16 A, so we recommend soldering thick wires directly to the connector-free version of the board and using **higher-current connectors** for applications that will exceed the terminal blocks' ratings.



Simple Motor Controller 18v7 bottom view with dimensions.



Simple High-Power Motor Controller 18v15 or 24v12 bottom view with dimensions.



Simple High-Power Motor Controller 18v25 or 24v23 bottom view with dimensions.

Warning: Take proper safety precautions when using high-power electronics. Make sure you know what you are doing when using high voltages or currents! During normal operation, this product can get hot enough to burn you. Take care when handling this product or other components connected to it.

People often buy this product together with:

Figure E.11: Pololu Simple High-Power Motor Controller 18v25.

Electronic Components ▸ Potentiometers ▸ Standard (24mm) Pots ▸ Philmore PC245

Philmore PC24 Philmore PC25

Philmore PC245

View Full-Size Image

Philmore PC245

(Philmore Manufacturing)

Your Price (each):

$2.73
List Price : $2.94

Ask a question about this product

Add to Cart **QTY:** 1

PHILMORE PC245 STANDARD 24MM 10K LINEAR POTENTIOMETER with SWITCH

These potentiometers are used in a wide variety of consumer electronics applications such as stereos, TV's, two-way radios, and many more. They are avalable with solder lug or universal terminal (combo) which may be inserted into PC boards or wrapped with wire and soldered.

- 24mm standard potentiometer
- 10K Ω linear taper
- Switch Rating: 1.0A @ 12 VDC or 125 VAC
- Combo lug
- Resistance tolerance = 20%
- Maximum Voltage = 500V AC
- Power Rating = 500 mA, .5W
- Total Rotation: 300°
- Rotation Life: 15,000 cycles
- Bushing diameter: 8mm
- Shaft: 30mm w/ flat 12mm

You need to Login in order to add this product to your Favorite List

Customer Reviews:

There are yet no reviews for this product.
Please log in to write a review.

Figure E.12: Philmore PC245 10K Ohm Linear Potentiometer Specifications.

NTE
ELECTRONICS, INC.
44 FARRAND STREET
BLOOMFIELD, NJ 07003
(973) 748–5089
http://www.nteinc.com

NTE5061A thru NTE5105A
(Includes NTE134A thru NTE151A)
Zener Diode, 1 Watt
±5% Tolerance

Features:
- Zener Voltage 2.4V to 200V
- Low Cost
- Low Zener Impedance
- Excellent Clamping
- Easily Cleaned with Freon, Alcohol, Chlorothene, and Similar Solvents

Maximum Ratings and Electrical Characteristics: (T_C = +25°C, unless otherwise specified. Single phase, half wave, 60Hz, resistive or inductive load, for capacitive load, derate current by 20%)

NTE Type Number	Nominal Zener Voltage V_z @ I_{zt}	Zener Test Current (I_{zt})	Maximum Dynamic Impedance			Maximum Leakage Current		Max DC Zener Current (I_{zm})	Max Forward Voltage	
			Z_{zt} @ I_{zt}	Z_{zk}	@ I_{zk}	I_R	@ V_R		V_F	@ I_F
	Volts	mA	Ω	Ω	mA	µA	Volts	mA	Volts	mA
NTE5061A	2.4	20.0	30	1200	0.25	100	1.0	–	1.1	200
NTE5062A	2.5	20.0	30	1250	0.25	100	1.0	–	1.1	200
NTE5063A	2.7	20.0	30	1300	0.25	75	1.0	–	1.1	200
NTE5064A	2.8	20.0	30	1400	0.25	75	1.0	–	1.1	200
NTE5065A	3.0	20.0	30	1600	0.25	50	1.0	–	1.1	200
NTE5066A	3.3	76.0	10	400	1.0	100	1.0	–	1.2	200
NTE134A	3.6	69.0	10	400	1.0	100	1.0	–	1.2	200
NTE5067A	3.9	64.0	9	400	1.0	50	1.0	–	1.2	200
NTE5068A	4.3	58.0	9	400	1.0	10	1.0	–	1.2	200
NTE5069A	4.7	53.0	8	500	1.0	10	1.0	–	1.2	200
NTE135A	5.1	49.0	7	550	1.0	10	1.0	–	1.2	200
NTE136A	5.6	45.0	5	600	1.0	10	2.0	–	1.2	200
NTE5070A	6.0	43.0	3.5	650	1.0	10	2.5	–	1.2	200
NTE137A	6.2	41.0	2	700	1.0	10	3.0	–	1.2	200
NTE5071A	6.8	37.0	3.5	700	1.0	10	4.0	–	1.2	200
NTE138A	7.5	34.0	4.0	700	0.5	10	5.0	–	1.2	200
NTE5072A	8.2	31.0	4.5	700	0.5	10	6.0	–	1.2	200

Figure E.13: NTE Electronics NTE142A Zener Diode Specifications.

Maximum Ratings and Electrical Characteristics (Cont'd): (T_C = +25°C, unless otherwise specified. Single phase, half wave, 60Hz, resistive or inductive load, for capacitive load, derate current by 20%)

NTE Type Number	Nominal Zener Voltage V_z @ I_{zt}	Zener Test Current (I_{zt})	Maximum Dynamic Impedance Z_{zt} @ I_{zt}	Maximum Dynamic Impedance Z_{zk} @ I_{zk}		Maximum Leakage Current I_R @ V_R		Max DC Zener Current (I_{zm})	Max Forward Voltage V_F @ I_F	
	Volts	mA	Ω	Ω	mA	μA	Volts	mA	Volts	mA
NTE5073A	8.7	29.5	4.75	700	0.5	10	6.5	–	1.2	200
NTE139A	9.1	28.0	5.0	700	0.5	10	7.0	–	1.2	200
NTE140A	10.0	25.0	7.0	700	0.25	10	7.6	–	1.2	200
NTE5074A	11.0	23.0	8.0	700	0.25	5	8.4	–	1.2	200
NTE141A	11.5	22.0	8.5	700	0.25	5	8.7	–	1.2	200
NTE142A	12.0	21.0	9.0	700	0.25	5	9.1	–	1.2	200
NTE143A	13	19.0	10	700	0.25	5	9.9	–	1.2	200
NTE144A	14	18.0	12	700	0.25	5	10.7	–	1.2	200
NTE145A	15	17.0	14	700	0.25	5	11.4	–	1.2	200
NTE5075A	16	15.5	16	700	0.25	5	12.2	–	1.2	200
NTE5076A	17	14.75	18	725	0.25	5	13.0	–	1.2	200
NTE5077A	18	14.0	20	750	0.25	5	13.7	–	1.2	200
NTE5078A	19	13.25	21	750	0.25	5	14.5	–	1.2	200
NTE5079A	20	12.5	22	750	0.25	5	15.2	–	1.2	200
NTE5080A	22	11.5	23	750	0.25	5	16.7	–	1.2	200
NTE5081A	24	10.5	25	750	0.25	5	18.2	–	1.2	200
NTE5082A	25	10.0	30	750	0.25	5	19.4	–	1.2	200
NTE146A	27	9.5	35	750	0.25	5	20.6	–	1.2	200
NTE5083A	28	9.0	37	775	0.25	5	21.7	–	1.2	200
NTE5084A	30	8.5	40	1000	0.25	5	22.8	–	1.2	200
NTE147A	33	7.5	45	1000	0.25	5	25.1	–	1.2	200
NTE5085A	36	7.0	50	1000	0.25	5	27.4	–	1.2	200
NTE5086A	39	6.5	60	1000	0.25	5	29.7	–	1.2	200
NTE5087A	43	6.0	70	1500	0.25	5	32.7	–	1.2	200
NTE5088A	47	5.5	80	1500	0.25	5	35.8	–	1.2	200
NTE5089A	51	5.0	95	1500	0.25	5	38.8	–	1.2	200
NTE148A	55	4.75	103	1750	0.25	5	40.7	–	1.2	200
NTE5090A	56	4.5	110	2000	0.25	5	42.6	–	1.2	200
NTE5091A	60	4.75	118	2000	0.25	5	44.9	–	1.2	200
NTE149A	62	4.0	125	2000	0.25	5	47.1	–	1.2	200
NTE5092A	68	3.7	150	2000	0.25	5	51.7	–	1.2	200
NTE5093A	75	3.3	175	2000	0.25	5	56.0	–	1.2	200
NTE150A	82	3.0	200	3000	0.25	5	62.2	–	1.2	200

Figure E.14: NTE Electronics NTE142A Zener Diode Specifications.

Maximum Ratings and Electrical Characteristics (Cont'd): (T_C = +25°C, unless otherwise specified. Single phase, half wave, 60Hz, resistive or inductive load, for capacitive load, derate current by 20%)

NTE Type Number	Nominal Zener Voltage V_z @ I_{zt}	Zener Test Current (I_{zt})	Maximum Dynamic Impedance			Maximum Leakage Current		Max DC Zener Current (I_{zm})	Max Forward Voltage	
			Z_{zt} @ I_{zt}	Z_{zk} @ I_{zk}		I_R @	V_R		V_F @	I_F
	Volts	mA	Ω	Ω	mA	μA	Volts	mA	Volts	mA
NTE5094A	87	2.9	225	3000	0.25	5	65.7	–	1.2	200
NTE5095A	91	2.8	250	3000	0.25	5	69.2	–	1.2	200
NTE5096A	100	2.5	350	3000	0.25	5	76.0	–	1.2	200
NTE151A	110	2.3	600	5000	0.25	0.5	80	9.1	1.0	1A
NTE5097A	120	2.1	700	5000	0.25	0.5	90	8.3	1.0	1A
NTE5098A	130	1.9	800	5000	0.25	0.5	95	7.7	1.0	1A
NTE5099A	140	1.8	900	5000	0.25	0.5	105	7.1	1.0	1A
NTE5100A	150	1.7	1000	5000	0.25	0.5	110	6.6	1.0	1A
NTE5101A	160	1.6	1100	5000	0.25	0.5	120	6.3	1.0	1A
NTE5102A	170	1.5	1200	5000	0.25	0.5	130	5.9	1.0	1A
NTE5103A	180	1.4	1300	5000	0.25	0.5	140	5.6	1.0	1A
NTE5104A	190	1.3	1400	5000	0.25	0.5	150	5.3	1.0	1A
NTE5105A	200	1.3	1500	5000	0.25	0.5	160	5.0	1.0	1A

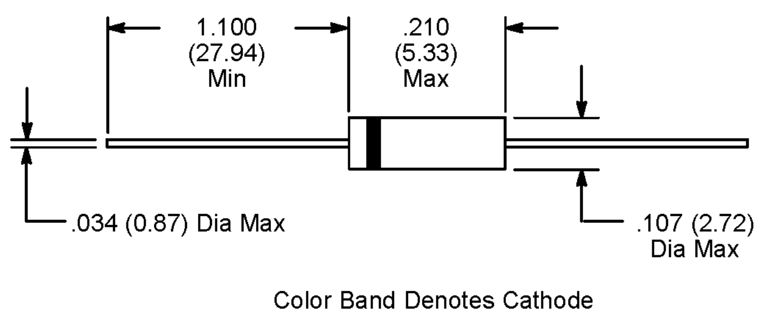


Figure E.15: NTE Electronics NTE142A Zener Diode Specifications.

Appendix F

Software

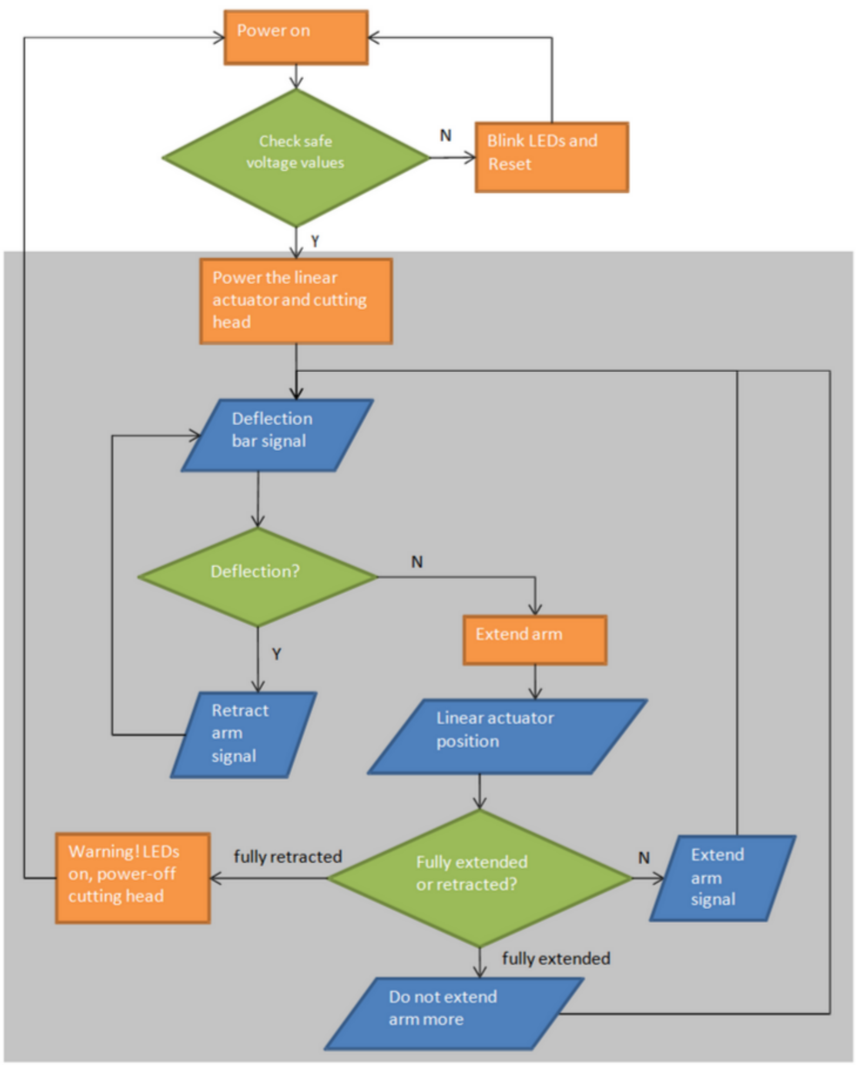


Figure F.1: Flowchart of coding logic.

```
#include <Servo.h>
#define servoPin 9 // pin to the motor controller
#define potPin A1  // pin to the potentiometer of sensor arm
#define B A2       // pin to the position of linear actuator along slider or stroke
Servo myservo;     // create servo object to control the linear actuator

//val -pwm value to send to the linear actuator
//pos -position of the linear actuator along the slide or scope
//ang -angle of deflection of sensor arm
//ang0 -angle of deflection at neutral position
int val, pos, ang, ang0;

void setup() {
  Serial.begin(9600);
  pinMode(servoPin, OUTPUT);   //sending pwm value
  pinMode(B, INPUT);           //receiving value
  pinMode(potPin, INPUT);      //receiving value

  ang0=(-5+analogRead(potPin));  //setting the initial angle
  delay(50);

  myservo.attach(servoPin);  // attaches the servo on pin 9 to the servo object
}
void loop() {
  // read values
  pos = analogRead(B);  //read position of linear actuator along stroke
  ang = analogRead(potPin);//read angle of sensor arm
  delay(10);

  val=map(ang, ang0, 250, 180, 0); //scaling the pwm value based on the deflection angle
  myservo.write(val);

  Serial.print("Position: ");
  Serial.print(pos);
  Serial.print(" \t Angle: ");
  Serial.println(ang);
  Serial.print(" \t Val: ");
  Serial.print(val);
}
```

Figure F.2: Arduino Script.

Appendix G

Electrical Optimization

After looking back at the results of the conducted tests, the main factor affecting performance was the speed of the linear actuator. Hence, it was concluded that faster extension and retraction times would yield faster mounting vehicle speeds and also more precise cutting paths. Figures G.1, G.2, and G.3 show possible alternative linear actuators that can be used in future iterations of the project. However, these linear actuators sacrifice load capabilities to increase arm speed, and so further analysis and testing should be conducted to determine the optimal linear actuator.

FIRGELLI AUTOMATIONS

High Speed Linear Actuators

High Speed Linear Actuators

$149.00

Force

22 lb

Stroke

2" 4" 6" 8" 10" 12" 18" 24" 28" 32" 36" 38"

ADD TO CART Qty: 1

Share:

Figure G.1: Firgelli Automations Linear Actuator Specifications.

These High Speed Linear Actuators offer fast speeds in many stroke options.

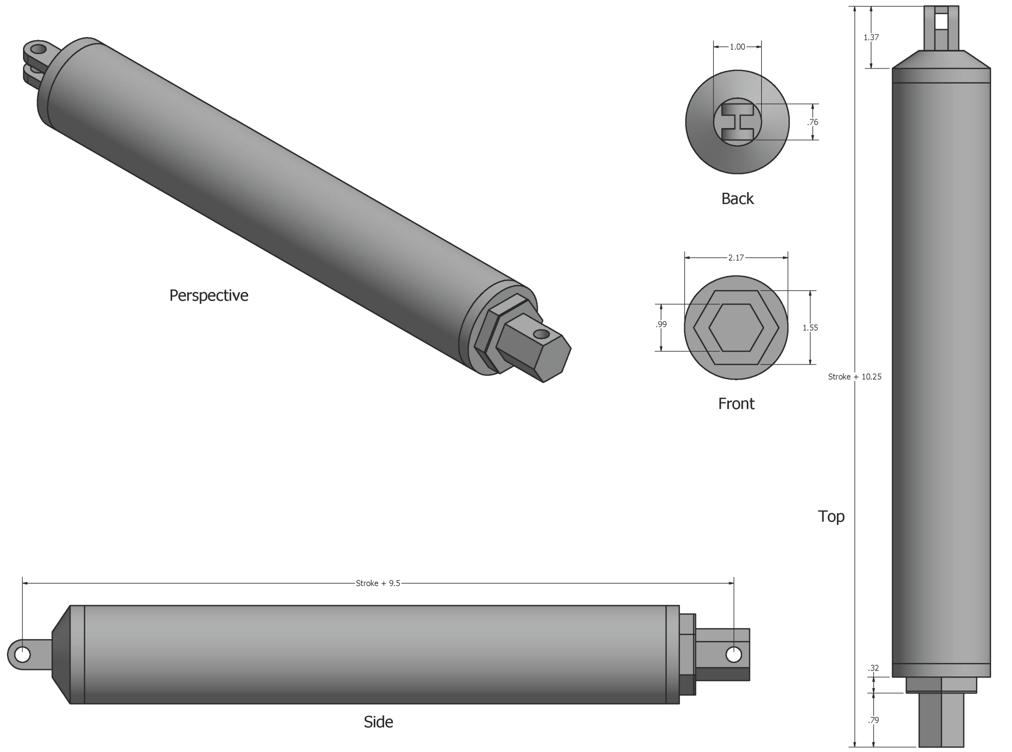
Description | Specifications | Technical Drawings | Product Videos

To adapt to the changing landscape of modern industry, the High Speed Actuator line was developed. Moving at a staggering 9 inches per second under no load, and 4.5 inches per second when at full capacity, this line of linear actuators are ready to serve any high speed application with ease. There is one variation of High Speed Actuator which we offer, which has a dynamic force of 22 lbs and a static force of 44 lbs. Featuring factory built-in limit switches, an aluminum casing to shed weight, and first rate internal materials to keep noise and vibration as low as possible. All this bundles together to serve up quiet, smooth, and reliable operation. As with all of our actuators, this line up comes with clevis mounting points on either end for simple and quick installment with the use of the MB8 Mounting Bracket.

Model	FA-RA-22-12-XX
Dynamic Force	22 lb
Static Force	44 lb
Speed ("/S)	4.5" (9" at no load)
Current	5A max
Duty Cycle	20% at 100% load, 50% at 25% of load
IP Rating	54
Input	12v DC
Operational Temperature	-26°C/65°C (-15°F/150°)
Limit Switch	Built-in (factory preset)
Safety Certifications	CE, ROHS
Bracket(s)	MB8

Stroke	Retracted Length	Extended Length	Weight
2"	11.5"	13.5"	3.5 lbs
4"	13.5"	17.5"	3.75 lbs
6"	15.5"	21.5"	4 lbs
8"	17.5"	25.5"	4.25 lbs
10"	19.5"	29.5"	4.6 lbs
12"	21.5"	33.5"	4.8 lbs
18"	27.5"	45.5"	6.0 lbs
24"	33.25"	61.25"	6.75 lbs
28"	37.25"	65.25"	7.25 lbs
32"	41.25"	69.25"	7.75 lbs

Figure G.2: Firgelli Automations Linear Actuator Specifications



Customer Reviews

No reviews yet! We just launched our new site, be the first to write a new review! Write a review

ABOUT FIRGELLI

Firgelli Automations is one of the original linear actuator and TV Lift manufacturers. Since 2004 we have been developing our own line of Linear Actuators, Track actuators, TV Lifts, Desk Lifts, and many other Motion control products to support many different industries.

Our products have been used in just about every application you can imagine from home automation to space exploration. Firgelli Automations is on the leading edge of Linear Actuator research and development, searching for innovative solutions to linear motion control.

Figure G.3: Firgelli Automations Linear Actuator Specifications

Appendix H

PDS

ELEMENTS/ REQUIREMENTS	UNITS	PARAMETERS DATUM	TARGET - RANGE
PERFORMANCE AND FEATURES			
Acceptable Cart Speeds	mph	N/A	1 to 3
Max operating angle (relative to cart bed)	deg's	~60	60
Overall weight of appendage (cart and battery not included	lbs	N/A	25-75
Arm reach from edge of cart	ft	N/A	0.5-3.5
Precision around stalk	inches	N/A	1-5
Max retraction speed	ft/s	N/A	0.2-0.5
Row width adaptability	Y/N	N/A	Y
Path-deviation adaptability	Y/N	N/A	Y
SAFETY			
Onboard killswitch	On/Off	N/A	Functional
Housing	Y/N	N/A	Y
Quality and Reliability			
Overall	years	N/A	10 with maintenance
Spool replacement	hours	N/A	72 (run time)
Standardized parts where possible	Y/N	N/A	Y
Row width adaptability	Y/N	N/A	Y
Wheel maintenance	---	N/A	After 1 session
Replace battery (run time)	hours	N/A	3-8

Figure H.1: AIRWT Product Design Specifications

Appendix I

Experimental Raw Data

	Operation Angle				
Deck	Plate	dh	Angle	Pivot-to-Pivot	33
14	8.25	-5.75	-9.88412		
12	24.5	12.5	20.74608		

Figure I.1: The results of the operation angle test (degrees).

	Weight (lbs)		
Linear Ac.	M. Plate	Elec.	Total
16.6	16.7	15.5	48.8
15.6	17.4	15.6	48.6

Figure I.2: The results of the weighing test.

Appendix J

Timeline

The following pages show the nine month timeline for the AIRWT project from October 2014 to June 2015.

Milestones	Description/Action Item(s)	Lead	Completion Date
Determine weed/root extraction method	*All team members will design/sketch 4 concept ideas for extraction mechanism*	TEAM	10/7/2014
Determine basic target specs for extraction mechanism	*Develop TVT in preparation for PKR*	TEAM	10/9/2014
Project Definition and Specification Report [DUE]	*Oral presentation and written report due*	TEAM	**10/14/2014**
Design concept mechanism	*Preliminary concept sketches*	TEAM	10/14/2014
Market Readiness Report [DUE] ("Info Gathering & Customer Needs")	*Written report due*	TEAM	**10/28/2014**
Preliminary design sign-off	*Design sign-off conducted in preparation of constructing and presenting product mock-up*	TEAM	10/28/2014
Visit testing venue, finalize target specs	*Further develop customer use case and refine concept models*	TEAM	10/30/2014
Design mechanism using CAD software	*CAD models will be presented following week for sign-off*	Baculi, Castrucci, Ding, Marit	10/31/2014
Acquire materials for construction of mockup		TEAM	11/4/2014
Begin construction of mockups		TEAM	11/4/2014
Determine functional groups/subgroups of mechanism	*Develop FFBD for the system in preparation for the CDR*	TEAM	11/6/2014
Sign-off on FFBD		TEAM	11/13/2014
Continue construction of mockup		TEAM	11/18/2014
Begin drafting CDR presentation; Draft CDR [DUE]		TEAM	**11/18/2014**
Finish construction of mockup		TEAM	11/25/2014

Sign-off on CDR presentation		TEAM	11/27/2014
Concept Mockup [DUE]		TEAM	**12/1/2014**
CDR Presentation [DUE]		TEAM	**12/1/2014**
Begin drafting CDR written report		TEAM	12/5/2014
Sign-off on CDR written report		TEAM	12/9/2014
CDR written report [DUE]		TEAM	**12/10/2014**
Agree on design of arm		TEAM	1/11/2015
complete parts list		TEAM	1/12/2015
Begin ordering Edison	*Talk to Kitts*		1/12/2015
Purchasing	*sensors, motors, electric weed whacker, linear actuator*	TEAM	1/13/2015
Purchasing	*cart, Edison expansion battery/additions*	Tyler/Marit	1/15/2015
Purchasing	*stock material, battery, misc parts*	TEAM	1/19/2015
CAD drawings of mount bracket to linear actuator		TEAM	1/19/2015
Flowchart		Gaston/Marit	1/19/2015
CAD drawings of slide and pivot		TEAM	1/23/2015
machine mounting bracket		TEAM	1/25/2015
Safety Assessment and Protocols		TEAM	1/26/2015
pseudo code		Gaston/Marit	1/26/2015
machine slider/servo holder		TEAM	2/1/2015
Detailed Drawings	*initial submit*	TEAM	2/2/2015
apply for Sr design conference	*fill out online survey*	TEAM	2/4/2015
CAD drawings of sensor mounts		TEAM	2/20/2015
CAD drawings of trunk sensor arm mount		TEAM	2/23/2015
Analysis Report		TEAM	2/23/2015
code		Gaston/Marit	2/23/2015
machine forcing sensor mounts		TEAM	2/26/2015
machining for assembly		TEAM	3/4/2015
Progress report	*formal written and oral*	TEAM	3/9/2015

Assembly Detailed Drawings	*final submit*	TEAM	3/18/2015
Spring Quarter			
final parts purchasing		TEAM	4/1/2015
ASN NO. 1 (Thesis, Drawing, Timeline)		*ASSIGNMENT*	4/1/2015
Tweek sensing arm design		TEAM	4/1/2015
contact vineyard about visits			4/2/2015
Posterboard for presentations		TEAM	4/4/2015
ASN NO. 2 (Resume, Com. Serv.)		*ASSIGNMENT*	4/6/2015
wiring/makerlab			4/7/2015
Preview Day Posterboard		TEAM	4/11/2015
Experimental protocol		TEAM	4/13/2015
Full prototype assembly		TEAM	4/15/2015
SEEDS presentation		TEAM	4/19/2015
Test at School	*basic movement*	TEAM	4/20/2015
Test At Vineyard 1		TEAM	4/24/2015
Societal/environmental impact		TEAM	4/25/2015
Societal/environmental impact presentation		*ASSIGNMENT*	4/27/2015
Test at VIneyard 2		TEAM	4/29/2015
Prepare for Conference		TEAM	5/1/2015
Update CDR		TEAM	5/1/2015
Finish CDR		TEAM	5/1/2015
In-class conference practice		TEAM	5/11/2015
In-class conference practice		TEAM	5/13/2015
Senior Design Conferences		TEAM	5/14/2015
Draft of final report due		*ASSIGNMENT*	5/20/2015
Patent research			5/22/2015
Patent research due		*ASSIGNMENT*	5/27/2015
Experimental results due		*ASSIGNMENT*	6/1/2015
OPEN HOUSE		*ASSIGNMENT*	6/1/2015
Finished written report due		*ASSIGNMENT*	6/10/2015

Appendix K

Expenses

AIRWT Bill of Materials				
Subsystem	**Item Name**	**Price**	**Quantity**	**Total**
Mounting Vehicle				
	Dolly	$ 84.97	1	$ 84.97
	Wood deck	$ 15.94	1	$ 15.94
	Shelf supports	$ 8.00	4	$ 32.00
Main Housing				
	Storage container	$ 9.99	1	$ 9.99
Retraction Mechanism				
	Linear actuator	$ 399.99	1	$ 399.99
	Super-duty mount	$ 34.99	2	$ 69.98
	12V battery	$ 58.96	1	$ 58.96
Weed Removal Attachment				
	Weed trimmer	$ 80.00	1	$ 80.00
	2' x 2' Wood sheet	$ 15.00	1	$ 15.00
	Castor wheels	$ 7.99	3	$ 23.97
	Shelf supports	$ 8.00	2	$ 16.00
Trunk Sensor				
	Potentiometer	$ 2.49	1	$ 2.49
	0.25" Clamping hub	$ 7.99	2	$ 15.98
	Swivel hub	$ 6.99	1	$ 6.99
	3' Aluminum rod	$ 20.00	1	$ 20.00
	Tension spring	$ 2.00	1	$ 2.00
Electronics				
	Intel Edison + Arduino BoB	$ 99.95	1	$ 99.95
	Solid-State Relays	$ 11.33	2	$ 22.66
	SSR heat sink	$ 5.30	2	$ 10.60
	9V batery	$ 3.49	1	$ 3.49
	Emergency Stop	$ 50.21	1	$ 50.21
	Toggle switch	$ 3.99	2	$ 7.98
	Switch covers	$ 3.99	2	$ 7.98
	Precision Digital Speed Controller	$ 99.99	1	$ 99.99
	5V Voltage regulator	$ 0.99	1	$ 0.99
Miscellaneous				
	Fasteners			$ 10.00
	Velcro			$ 2.50
	Thermal paste			$ 8.00
	Wires			$ 30.00
	Heat shrink			$ 10.00
	Solder			$ 1.00
	Ring lugs			$ 1.00
	Misc. acryllic			$ 1.00
	Misc. aluminum			$ 15.00
	Misc. wood			$ 5.00
	Misc. electronic components			$ 75.00
TOTAL				**$ 1,316.61**

Figure K.1: The cost to produce one AIRWT prototype.

Appendix L

Business Plan

A business plan was created for the hypothetical volume manufacturing and distribution of the AIRWT system. The following pages show the page by page business plan submitted to Dr. Timothy Hight.

Automated In-Row Weed Trimmer
Bay Area Enterprise

Business Development Plan

May 24th, 2015

Abstract

Bay Area Enterprise (BAE) designs and manufactures the Automated In-Row Weed Trimmer (AIRWT), an automated weed removal system designed to be used in vineyards in order to enable safe and efficient removal of weeds while preventing damage to the vines. The goal of the system is to reduce the need for the use of manual labor and herbicides while improving production rates of grapes.

By implementing an automated system for weed removal, BAE seeks to resolve ethical issues in food production, primarily current problems surrounding human labor, environmental friendliness, and social sustainability.

The focus of this document is to explore BAE's business development plan.

Contents

Introduction

I. Overview

Weeds in organic vineyards compete with crops for water and nutrients. They are expensive and labor-intensive to remove. An automated weed removal system would reduce the need for the use of manual labor and herbicides while improving crop production rates.

Non-organic vineyards utilize chemical methods such as herbicides to deal with weeds. Herbicides are a more cost and time effective means of dealing with weeds compared to non-chemical methods such as hand hoeing, cultivating, and mowing due to the simplicity of its execution. With herbicides, a vineyard owner can quickly make rounds through the rows, spraying in general vicinities with confidence in the method's thoroughness. Spraying is also much less manually taxing than pulling out the weeds by hand as all that needs to be done is essentially point and shoot. This allows herbicides to be used in a variety of terrain, such as hillsides, where a worker rather than a whole vehicle can simply walk down the row spraying.

In addition, automated devices are playing an increasingly larger role in society. By implementing automated solutions in the agriculture industry, these devices will address several societal and ethical issues, including meeting the demands of an ever-increasing population, reducing the need for intensive human labor, and limiting negative environmental impacts for increased sustainability.

II. Product and Market

BAE currently produces one solution – the Automated In-Row Weed Trimmer (AIRWT).
The AIRWT seeks to reduce the need for manual labor and herbicides while improving production rates of grapes by automating the weed removal process at vineyards. By implementing an automated system for weed removal, the product aims to resolve ethical issues in food production, primarily current problems surrounding human labor, environmental friendliness, and social sustainability.

The product in its current state achieves the following:

1) Comparable performance levels to flat-plane weed removal mechanisms when functioning on sloped/terraced vineyards
2) Function under electric power sourced from environmentally friendly resources
3) Propose a significant value proposition compared to competitive products
4) Achieves semi-autonomous functionality, and perform consistently with limited operator supervision

5) Remains adaptable for different environments including but not limited to different terrain, elevations, weather conditions, and vineyard sizes

III. Personnel

Currently, BAE is staffed by employees:

1) Two Mechanical Design Engineers
2) One Product Design Engineer who doubles as the lead Business Strategist.
3) One Control Systems Engineer
4) One Mechatronics Engineer

IV. Competitive Analysis Overview

Currently, there is no direct competitor to the AIRWT system based on both functionality and price point. The AIRWT system is currently the only semi-autonomous or fully autonomous weed removal system able to operate on hillsides and function as a standalone system.

However, there are corporations that do produce similar equipment, but at a significantly higher price point. A more in-depth competitive analysis will be conducted later in this document.

V. BAE Mission Statement

BAE is an engineering firm that seeks to design and manufacture environmentally-friendly, cost-effective semi-autonomous and fully autonomous weed removal systems for organic vineyards to facilitate efficient and effective weed removal without any damage to vines. These products will be designed with a high degree of adaptability and scalability for future expansions into different sized operations and different agricultural sectors while decreasing the need for manual labor, providing a significant cost advantage to smaller sized operations.

By producing such systems, BAE hopes to address ethical issues in food production, primarily current problems surrounding human labor, environmental friendliness, and social sustainability.

BAE Products

I. Product Specifications

Based on market segment needs, the BAE has designed its products to achieve the following:

1) Function as *standalone systems*, meaning that the system operates without the need of a tractor and power take-off unit.
2) Autonomously or semi –autonomously remove weeds.
3) Operate on sloped/terraced environments.
4) Draw power from clean, renewable energy sources.
5) Remain adaptable for scale-up/scale-out opportunities as well as adaptation for different agricultural sectors.
6) Cost under $2,500.

II. AIRWT System Overview

BAE's first product, the AIRWT, consists of the following six key components to achieve the product specifications:

1) Retraction mechanism
2) Weed removal attachment
3) Mounting Vehicle
4) Sensor
5) Microcontroller and supporting electronics/software
6) Main housing

The *retraction mechanism* will facilitate the lateral movement of the device. Paired in conjunction with the sensor, microcontroller, and supporting electronics/software, the retraction mechanism will enable the safe removal of weeds and prevent any harm to the vines.

The *weed removal attachment* serves to trim the weed during the operation cycle (per request of the customer), and will draw power from the onboard power source.

The *mounting vehicle* consists of a push cart with a wooden deck affixed to it. This will provide the base on which all other components will be attached to.

The *sensor* will be attached externally to the housing, and will protrude a certain distance from the edge of the device. If the sensor makes contact with a vine during the cultivation process, then it will detect resistance and work in conjunction with the retraction mechanism, microcontroller, and supporting electronics/software to facilitate movement of the retraction mechanism in such a manner that will enable the safe removal of weeds and prevent any harm to the vines.

The *microcontroller and supporting electronics/software* will be used in conjunction with the retraction mechanism and sensor to facilitate movement of the retraction mechanism in such a manner that will enable the safe removal of weeds and prevent any harm to the vines. Software for the microcontroller will be developed so that it will receive sensor resistance as input, and output movement commands for the retraction mechanism. In addition, the electronics subsystem will include all power sources to supply power to both the cutting tool and electronics.

The *main housing* will serve as an enclosure to host all subsystems as well as provide an attachment point for those subsystems that will be mounted externally.

Figure 2.1 shows a general schematic of the AIRWT system.

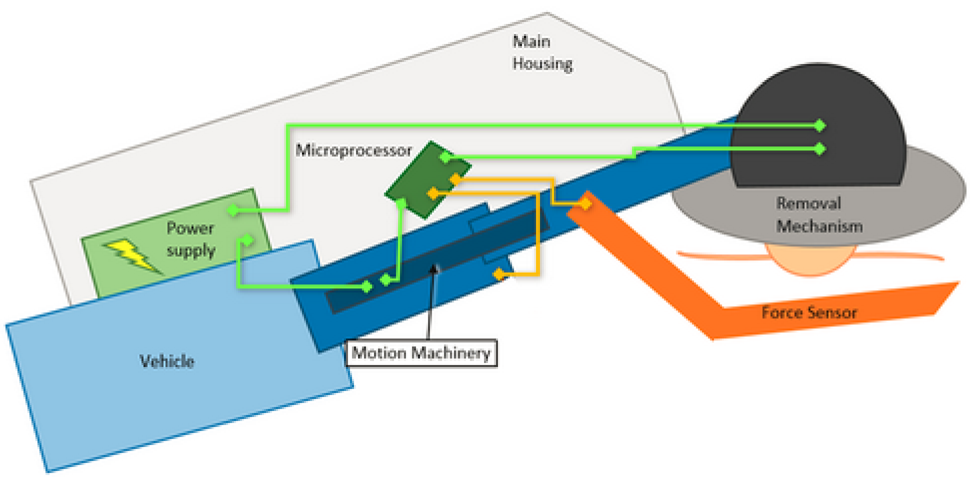


Figure 2.1. A general schematic of the AIRWT showing its major subsystems

III. System Benefits

Perhaps the most important functionality of the AIRWT system is its ability to perform consistently on sloped and terraced environments. Currently, there are no mechanical system, automated or otherwise, that will perform weed removal on sloped environments. The closest competitors to the AIRWT system are conventional automated in-row tillers and mowers, which only operate on flat land. By focusing on the ability to function in sloped and terraced environments, the AIRWT presents a large value proposition to vineyards by offering a two-in-one weed removal solution.

In addition, current conventional automated in-row tillers and mowers require significant capital and operating expenses to run. As a result, this leaves only the most well-established of vineyards able to afford the operation of such machinery, putting smaller vineyards at a significant disadvantage.

Those at the largest disadvantage are organic vineyards, which are barred from using herbicides as a weed removal method. As a result, small organic vineyards are constrained to resorting to manpower to remove weeds, which is both a time-consuming and labor-intensive process; any time focused on weed removal for these vineyards is time lost to other vital activities, including infrastructure development and crop management.

With these disadvantages in mind, BAE decided to focus on small organic vineyards as a primary user base. Noting that an increasing number of "startup" vineyards are turning to organic farming methods, AIRWT provides a cost-effective, scalable weed removal solution that eliminates the need for herbicides and manpower. This furthers AIRWT's value proposition, and separates it from the competition as a cutting-edge, environmentally-conscious food production solution.

Market Opportunities

I. Market Analysis

According to recent statistics, there are currently 7,042 wineries in the United States alone[1]. According to a popular wine purchasing site, there are 14,000 wineries registered with the site[2]. Understanding that the actual number of wineries in Europe could be significantly higher, for lack of better data, it is assumed that the total pool of wineries is 21,000.

One of the closest competitive products to the AIRWT system is the Weed Badger, which sells for at least $4,000[3]. For ease of calculation, it will be assumed that the MSRP for a new unit is $5,000. Knowing that the Weed Badger company generates revenue between $2.5 and $5 million a year[4], we can determine that the Weed Badger company sells anywhere between 500 and 1000 units a year.

Other competitor corporations, like Pellenc, have recorded $126 million in revenue[5], with tillers and cultivators selling for $10,500 in used condition[6]. For ease of calculation, it is assumed that the MSRP on a new unit is $15,000, and that only ten percent of Pellenc's revenue is from weeder sales. Performing the calculations, it is determined that Pellenc sells 840 units per year.

From just two manufacturers, it is found that an average of 1,800 weeder units are sold per year. However, acknowledging that the AIRWT system has several other competitors, it can be assumed that 2,500 weeder units are sold yearly around the world.

II. BAE's Entry Into Market

BAE currently has a customer based on a small hillside organic vineyard in the Gilroy, California area. The customer is surrounded by several other wineries that also organically farm grapes; the customer claims that he maintains close contact with these other wineries.

As stated previously, BAE intends on focusing on small organic vineyards as its entry in the agriculture equipment industry. By establishing several customer success stories and a well-founded customer network, BAE will expand into producing more sophisticated go to market solutions that are highly adaptable and scalable. This will ensure that BAE will be able to cater to a multitude of customers with different requirements, and as a result, different product specifications.

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[1] http://www.statista.com/statistics/259365/number-of-wineries-in-the-us-by-state/

[2] http://www.wineweb.com/mapeuro.cfm

[3] http://www.tractorhouse.com/listingsdetail/detail.aspx?OHID=9221879

[4] http://www.manta.com/c/mm2k9j7/weed-badger

[5] http://www.somfy.com/group/index.cfm?contentid=DA548DBB-B82A-FE57-2DE14663381B09B3&language=en-en

[6] http://www.vinetechequipment.com/Used-Equipment.htm

Competitive Analysis

I. Falconero Group

Falconero is an Italian company that produces several in-row tillers[7]. Its flagship tiller, the Frese, uses a force sensor to detect any obstructions in the path of the tiller, and will prompt the driver to move the arm inward.

A used Falconero tiller was found with a listing price of $4,851[8]; it can be anticipated then that the MSRP of a brand new tiller is higher, and the team estimates the MSRP to be $6,000.

The manufacturer makes no claims in regards to sales volumes of its product; however it does appear that their major sales are focused in Spain and Italy.

II. Spedo

Spedo is another Italian company that produces the Marte and Mercurio in-row tillers[9]. Like the Falconero line, the Spedo also uses a force sensor that will prompt the driver to move the cutting tool inward once it detects an obstruction.

While there is no datum available to provide insights into the sales volume of Spedo products, it does appear that Spedo has North American distributors, as well as selling products to "Portugal, Spain, Germany, Slovenia, Australia, Argentina, [and] Chile."[10]

III. WeedBadger® Company

WeedBadger® is a USA-based company that produces an entire line of tillers.[11] In addition, its products offer a large degree of versatility by presenting the options for multiple mounting platforms as well as different cutting tool attachments.

WeedBadger® also use force sensors to detect obstructions and prevent the cutting tool from damaging actual crops.[12]

---

7 http://www.falconero.com/index.php

8 http://www.machinio.com/listings/5433581-Used-FALCONERO-TIGRE-200-in-Whakatane-Bay-Of-Plenty-New-Zealand

9 http://www.italianfarmmachinery.com/company_details.asp?id=121

10 http://www.italianfarmmachinery.com/company_details.asp?id=121

11 http://www.weedbadger.com/contact.php

12 http://www.weedbadger.com/pdf/WeedBadgerCatalog_LR.pdf

IV. Kimco Manufacturing

Kimco Manufacturing is a company headquartered in Fresno, California. Their in-row tiller, the Model 9300, is a versatile platform that can be mounted a number of ways in order to accommodate different row widths. Furthermore the Model 9300 possesses a system that actually senses incoming vine stalks and sends signals to automatically retract the tiller.[13]

This feature, however, comes at a steep price. A heavily used Model 9300 has been quoted at $6,000 with new models being cited as high as $20,000.[14]

V. Pellenc

Pellenec is a French company that produces the in-row tiller the Tournesol.[15] Unlike other in-row tillers, the Tournesol operates automatically without using any force sensors. This tiller features a toothed gear that conforms to the shape of a vine stalk which sits upon the rotary tiller. The gear pushes the entire spring-loaded contraption away from the vine stalk, causing the blades to narrowly avoid the stalks.

Like the Model 9300, the Tournesol comes at a steep price of $21,000.[16] Furthermore, the Tournesol assumes as certain stalk thickness, and anything that is thinner will be nicked by the blades.

A complete WeedBadger system was found to have a used retail price of $4,695.[17] Like the Falconero system, the team anticipates that the MSRP for a new system will approach $6,000.

[13] http://www.kimcomfg.com/9300.html
[14] http://www.wineindustryclassifieds.com.au/classified/kimco-model-9300-vine-row-weedertiller-listing-3176.aspx#.VGQjgvlENjI
[15] http://www.pellenc.com.au/#!tournesol/c10s3
[16] http://www.lakeviewvineyardequipment.com/product/pellenc-tournesol-mechanical-weeder/
[17] https://equipmentalley.com/main/listing/Weed-Badger-4020-SST/662257

VI. General Observations on the Competition

The aforementioned competitors produce highly sophisticated automated weed removal systems that are able to operate with limited supervision. However, none of them are standalone systems in that they require an additional mounting vehicle (i.e. tractor or Skid Steer loader) for proper operation. This not only introduces a sizeable additional overhead cost, but also increases operating expenses due to the need for diesel fuel. Furthermore, the use of a diesel tractor increases the detrimental impact on the environment due to emissions.

Table 1.1 shows a general comparison between the AIRWT system and several competitor products.

Table 1.1. Comparison of features between the AIRWT and several competitor products.

	Force Sensor Assisted	Multiple Mounting Types	Removal Method	Standalone System	Function on Slopes	Estimated MSRP
AIRWT	Yes	No	Trim	Yes	Yes	$4,000
Falconero	Yes	No	Cultivate	No	No	$6,000
Weed Badger	Yes	Yes	Cultivate/Trim	No	No	$6,000
Kimco Mfg. Model 9300	Yes	Yes	Cultivate	No	No	$20,000
Pellenec Tournesol	No	Yes	Cultivate	No	No	$21,000

Sales and Marketing Strategies

It is BAE's belief that the best advertising is achieved through customer success stories and thus establishing a solid customer base. That said, to further promote BAE's products, the team will establish a website and advertise on farming equipment sales websites.

The team would like to keep its personnel to an absolute minimum, and as several team members are also very well-versed in business skills, they will function also as marketers and sellers. One tactic that the team foresees on employing is visiting several vineyards and wineries for tastings and observing the needs of that particular vineyard. In the event that the team does manage to sustain a conversation with a vineyard employee, the team will introduce BAE products and offer compelling reasons as to why BAE products are market segment leaders in vineyard weeding equipment.

In the early stages of BAE's production, the team plans to either ship units disassembled or personally deliver units (if the customers are local) directly from the factory. With increased demand, the team may explore other methods of distributions such as resellers and satellite factories/assembly areas.

Financial Analysis

Table 6.1 shows the Bill of Materials (BOM) for the AIRWT system, and effectively shows the cost of one unit (excluding the cost of labor to manufacture parts and assemble the unit).

Table 6.1. Bill of Materials (BOM) of the AIRWT system showing all components costs (excluding costs to manufacture and assemble components).

AIRWT Bill of Materials				
Subsystem	**Item Name**	**Price**	**Quantity**	**Total**
Mounting Vehicle				
	Dolly	$ 84.97	1	$ 84.97
	Wood deck	$ 15.94	1	$ 15.94
	Shelf supports	$ 8.00	4	$ 32.00
Main Housing				
	Storage container	$ 9.99	1	$ 9.99
Retraction Mechanism				
	Linear actuator	$ 399.99	1	$ 399.99
	Super-duty mount	$ 34.99	2	$ 69.98
	12V battery	$ 58.96	1	$ 58.96
Weed Removal Attachment				
	Weed trimmer	$ 80.00	1	$ 80.00
	2' x 2' Wood sheet	$ 15.00	1	$ 15.00
	Castor wheels	$ 7.99	3	$ 23.97
	Shelf supports	$ 8.00	2	$ 16.00
Trunk Sensor				
	Potentiometer	$ 2.49	1	$ 2.49
	0.25" Clamping hub	$ 7.99	2	$ 15.98
	Swivel hub	$ 6.99	1	$ 6.99
	3' Aluminum rod	$ 20.00	1	$ 20.00
	Tension spring	$ 2.00	1	$ 2.00
Electronics				
	Intel Edison + Arduino BoB	$ 99.95	1	$ 99.95
	Solid-State Relays	$ 11.33	2	$ 22.66
	SSR heat sink	$ 5.30	2	$ 10.60
	9V batery	$ 3.49	1	$ 3.49
	Emergency Stop	$ 50.21	1	$ 50.21
	Toggle switch	$ 3.99	2	$ 7.98
	Switch covers	$ 3.99	2	$ 7.98
	Precision Digital Speed Controller	$ 99.99	1	$ 99.99
	5V Voltage regulator	$ 0.99	1	$ 0.99
Miscellaneous				
	Fasteners			$ 10.00
	Velcro			$ 2.50
	Thermal paste			$ 8.00
	Wires			$ 30.00
	Heat shrink			$ 10.00
	Solder			$ 1.00
	Ring lugs			$ 1.00
	Misc. acryllic			$ 1.00
	Misc. aluminum			$ 15.00
	Misc. wood			$ 5.00
	Misc. electronic components			$ 75.00
TOTAL				**$ 1,316.61**

During the initial phases of BAE's operations, each team member will be compensated $55,000 annually. Each of the five team members will perform multiple functions, including

1) Assembly of units
2) Designing, testing, and implementing improvements to systems
3) Conducting business operations (sales, marketing, and finance)

BAE will initially base its operations out of a Santa Clara, California warehouse, which charges a monthly rental rate of $0.95 per square feet of space[18]. The warehouse currently boasts 8,316 sqft of space, which yields a $95,000 yearly lease rate. This warehouse will allow room BAE for expansion.

For beginning its operations, BAE will need to acquire several pieces of equipment including two Bridgeport-type milling machines, an engine lathe, floor drill press, and laser cutter. Prices for used mills[19] and lathes[20] hover around $5,000; drill presses may be purchased for as little as $500 new[21], and laser cutters sell for $11,000 new[22]. Miscellaneous equipment (attachments for machines, basic hand tools, etc.) and expendable items (rags, cooling fluid, etc.) are expected to cost another $5,000. These costs will be included as part of the overhead to kick-start BAE.

Other overhead costs include one year's rent and utilities for the manufacturing facility, one year's salary for the team, and basic office supplies, electronics, and software for the team to carry out its operations. All overhead costs are documented in Table 6.2.

Table 6.2. Overhead costs associated with BAE's initial operations.

Item	Unit Cost ($)	Quantity	Total Cost ($)
Mills	5,000	2	10,000
Lathe	5,000	1	5,000
Drill Press	500	1	500
Laser Cutter	11,000	1	11,000
Misc. Equipment	5,000	1	5,000
Salary	55,000	5	275,000
Office Equipment	15,000	1	15,000
Rent	95,000	1	95,000
Utilities	120,000	1	120,000
AIRWT Inventory	1,500	5	7,500
Total			**544,000**

[18] http://www.loopnet.com/Listing/19086452/2971-Mead-Avenue-Santa-Clara-CA/
[19] http://www.sterlingmachinery.com/listing.php?cat=Milling+Machines&subcat=Vertical+%28Bridgeport+Type%2
[20] www.sterlingmachinery.com/listing.php?cat=Lathes&subcat=Engine
[21] http://thd.co/1EukHVi
[22] https://www.bosslaser.com/boss-ls-3650.html

Assessing the total overhead costs in Table 6.2, it seems reasonable to seek a $600,000 initial investment (which can come from a mix of loans and direct investments from stakeholders), with the extra $56,000 invested to serve as a contingency fund for unforeseen circumstances.

BAE intends on selling 250 units per year, which is half the number of units that WeedBadger® Company sells (incidentally, the WeedBadger® Company employs between ten to nineteen people). Even with the AIRWT priced at a considerably lower $4,000 compared to all other systems on the market (which are also not standalone), BAE is still able to reap a $2,500 profit on each unit it sells.

Table 6.3 shows a yearly revenue and profit analysis for BAE.

Table 6.3. Revenue and profit analysis for BAE's operations on an annual basis.

Item	Unit Price ($)	Quantity	Loss/Gain	Total
AIRWT MSRP	3,500	250	Gain	1,000,000
Revenue				1,000,000
AIRWT Cost	1,500	250	Loss	375,000
Salary	55,000	5	Loss	275,000
Rent	95,000	1	Loss	95,000
Utilities	120,000	1	Loss	120,000
Profit				**135,000**

At an annual production rate of 250 units, and assuming that the business does not grow, stakeholders may expect a full return on investment in under five years. However, it is BAE's hope that production will increase to 500 units per year by the third year of operations as well as diversify their product offerings to include more sophisticated solutions that may sell with a higher profit margin.

Manufacturing Plan

For at least the first year of operations, BAE will hand build all AIRWT units. However, with BAE expects to reinvest its profits into further developing the business by automating its manufacturing process through designing and developing tooling, fixtures, and machinery to enable more efficient assembly.

The team understands that manpower may be spread thin in the initial few months of the operation, and expects to keep at least ten AIRWT units in inventory as so to reduce manufacturing lead times in case a customer orders multiple units, or the team is too occupied with business development activities.

Once the current warehouse reaches or exceeds maximum production capacity, the team will seek a secondary location to continue manufacturing operations. At that point, the team expects to be seeing enough revenue so that it may be able to pay the operating expenses for a larger location that will support the assembly of larger, more sophisticated machines.

Services and Warranties

BAE will offer a two year limited warranty on the AIRWT system, which does not cover expendable items (i.e. the trimmer line, batteries, and mounting vehicle tires). If a major component does fail within the two years, the team will either repair or replace the system, depending on which option is most cost-effective for the team.

Once a system has fallen out of warranty, BAE will offer repair services billed at $50 per hour per technician. In addition, replacement parts will be sold at a 15% markup in order to recoup costs associated with acquiring the part as well as improve profit margins for servicing.

Appendix M

Senior Design Conference

The 45^{th} annual Senior Design Conference was held on May 14,2015. The AIRWT team presented in the Mechanical Engineering Session 2, held in the the Benson Center, Williman Room from 3:25-4:00 PM. The proceeding sections show the slides presented during the conference as well as the final scores given by the judges.

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Automated In-Row Weed Trimmer (AIRWT)

Joshua Baculi
Tyler Castrucci
Joshua Ding
Marit Knapp
Gaston Young

Santa Clara University 2015 Senior Design Conference

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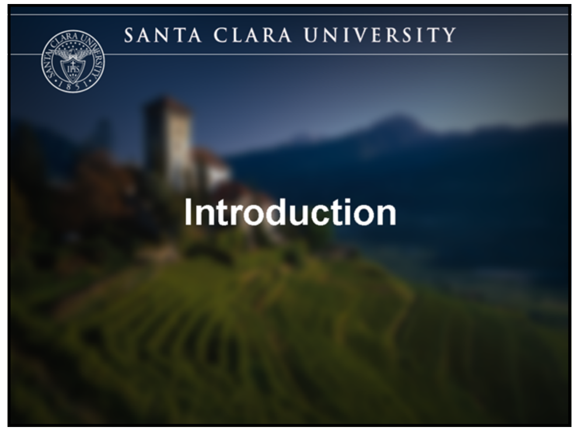

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The AIRWT System

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Executive Summary

- Customer Use Case
- Project Vision and Scope
- Product Goals
- Test Results
- Future Development and Testing Plans

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AIRWT Mission Statement

- Reduce the need for the use of manual labor and herbicides
- Improve production rates of grapes
- Automating the weed removal process

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Project Motivation

- Interest in design and controls
- Need for an automated weed-trimmer capable of operating on a hillside
  - Weeds steal nutrients, shelter pests, increase disease incidence
  - Organic is popular but costly
  - Automated systems are efficient, but none operate at an incline

Pesticide Herbicide

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Proposed Advantages

- Economic
  - Allow small organic vineyards to gain a competitive edge on larger vineyards
- Environmental
  - Zero emissions, fully electric system
  - Eliminates needs for herbicide use on vineyards
- Sustainable System
  - Rechargeable batteries

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Proposed Advantages

- Health and Safety
  - Eliminates need for intensive manual labor (and risk for injury using hand tools)
  - Reduces risk for inhaling toxic chemicals (herbicides)
- Social
  - more efficient farming to address the demands of an increasing population

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Design Process

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Design Requirements / Constraints

- Timing
  - 9 month product development cycle
    - limited scope
- Requirements for off the shelf/easily manufacturable parts
  - Limited custom fabrication → cheaper overall system
- Requirements for automation
  - Dictated need for sensor system, control system, and retracting system
- Need for environmentally sustainable system
  - Identified need for a fully rechargeable electric system

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Design Requirements / Constraints

- Customer requirement for weed removal via trimming
  - Led to use of an off the shelf weed wacker head
- Customer requirement to function on sloped environments
  - Dictated need for 3 DOF plane system

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Target Specifications

ELEMENTS/ REQUIREMENTS	UNITS	PARAME TERS DATUM	TARGET - RANGE
PERFORMANCE AND FEATURES			
Acceptable Cart Speeds	mph	N/A	1 to 3
Precision around stalk	inches	N/A	1-5

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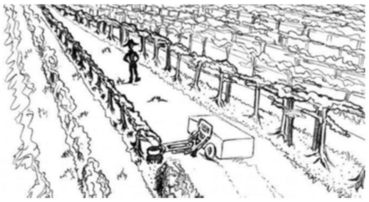
Product Concept Generation



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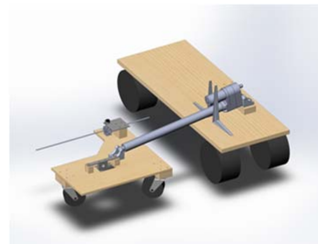
Product Concept Generation



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Sensor Arm Pivot Concept

- Three main requirements for sensor arm assembly
  - Sensor arm must proceed the cutting head
  - Three wheels for balance
  - One wheel must be outside the cutting head

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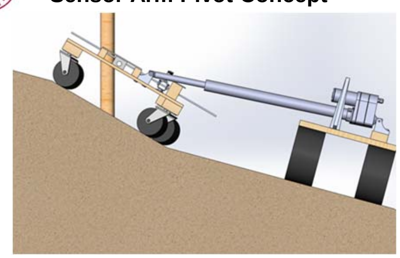
Sensor Arm Pivot Concept



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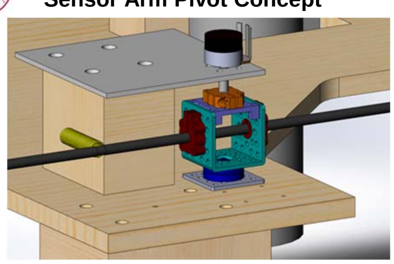

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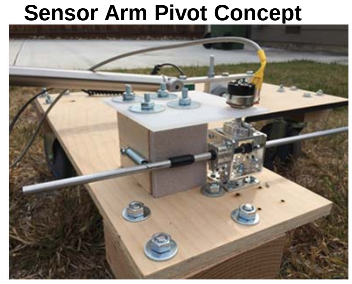

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Cutting Head Mounting Concept

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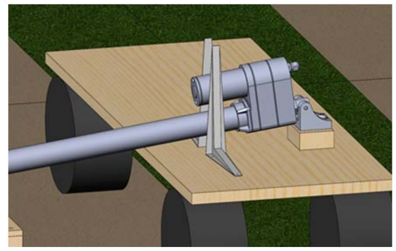
Linear Actuator Guides



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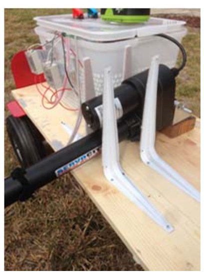

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Finite Element Analysis (FEA)

- Primary design concerns
  - Sensor Arm
  - Mounting plate
- All parts passed FEA

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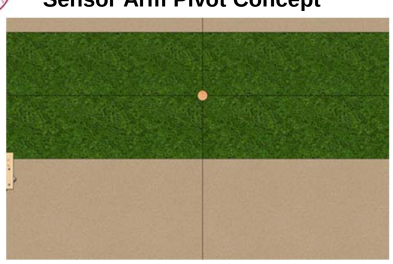

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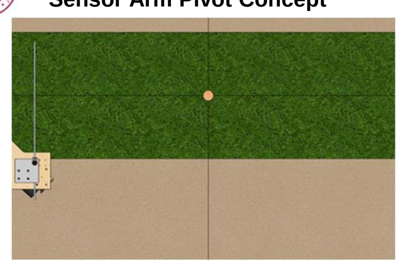

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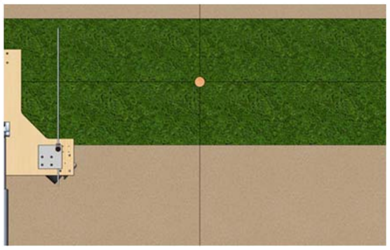

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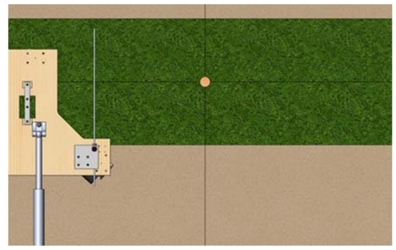

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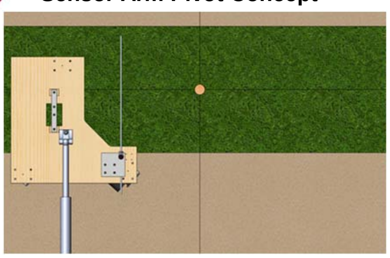

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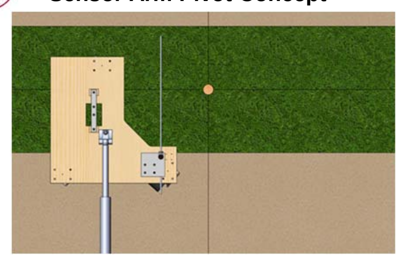

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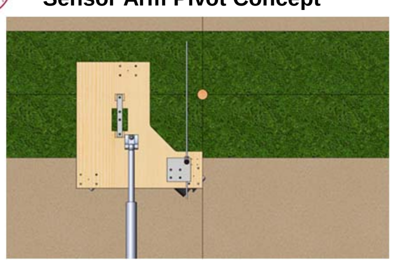

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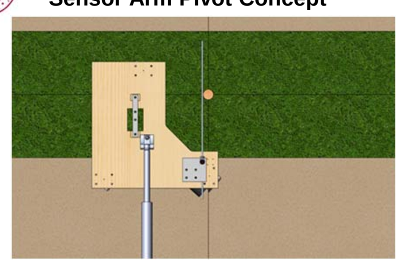

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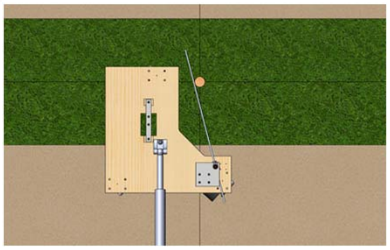

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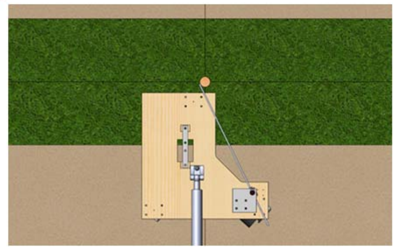

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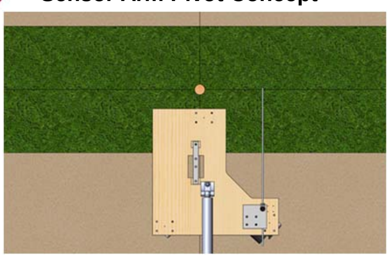

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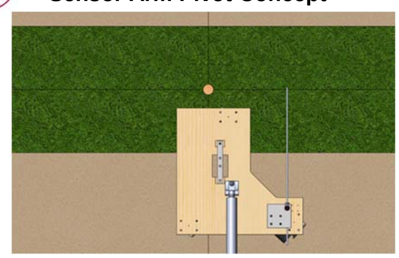

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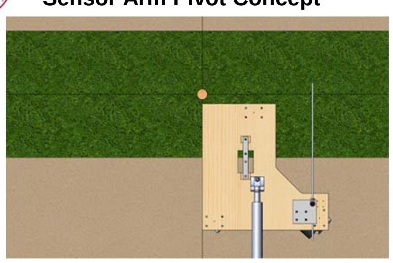

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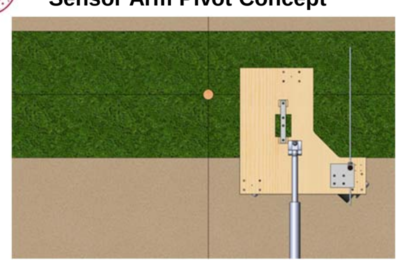

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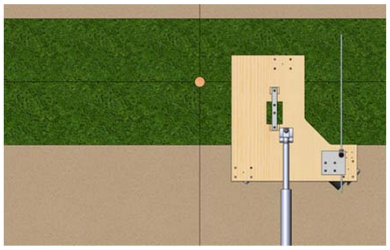

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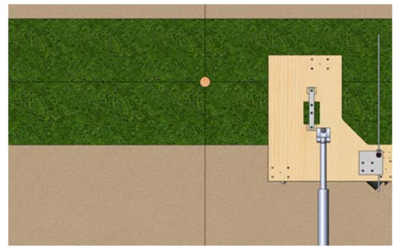

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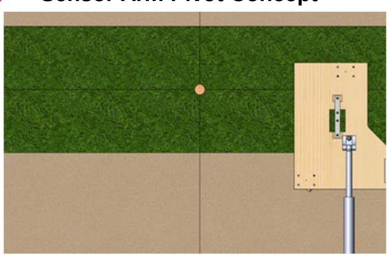

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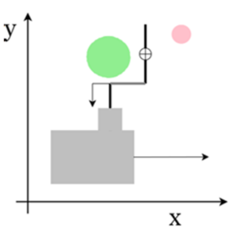
Equation of Motion



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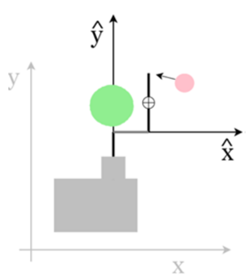

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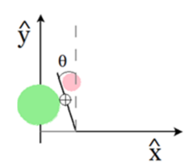

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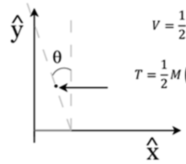
Equation of Motion



$$V = \frac{1}{2}k\theta^2$$

$$T = \frac{1}{2}M\left(\frac{L}{2}\right)^2\dot{\theta}^2$$

$$\ddot{\theta} + \frac{k}{M(L/2)^2}\theta = \frac{k}{M(L/2)^2}r(t-\tau)$$

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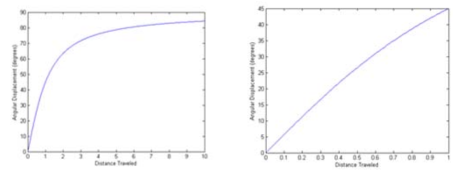
Equation of Motion



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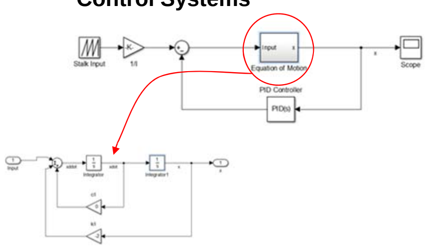
Control Systems



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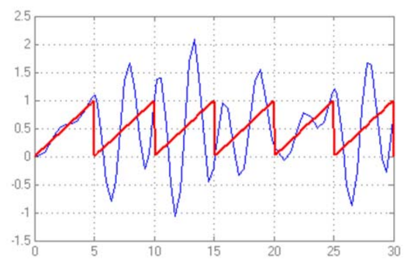

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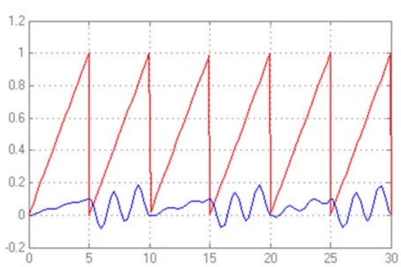
Control Systems



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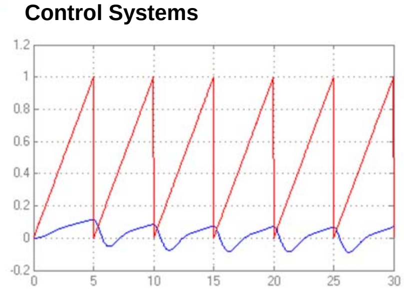
Control Systems



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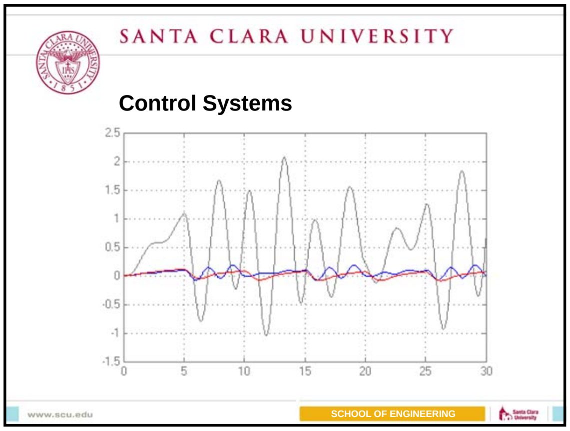
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Control Systems
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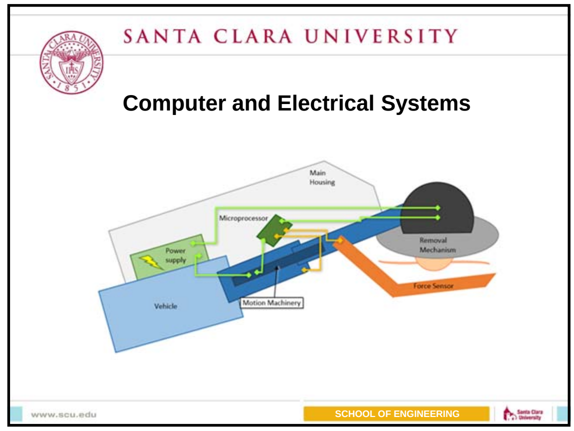
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Computer and Electrical Systems
Main Housing
Microprocessor
Power supply
Removal Mechanism
Vehicle
Motion Machinery
Force Sensor
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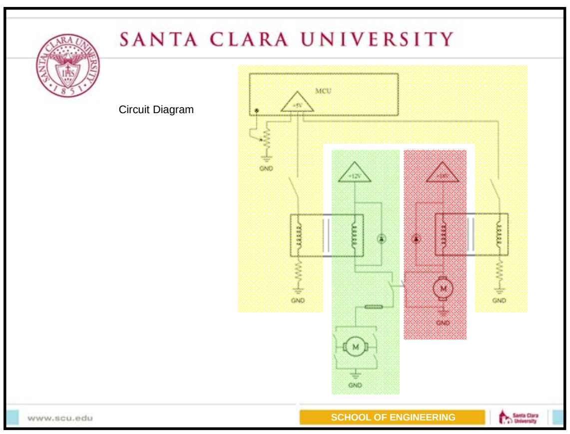
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Circuit Diagram
MCU
GND
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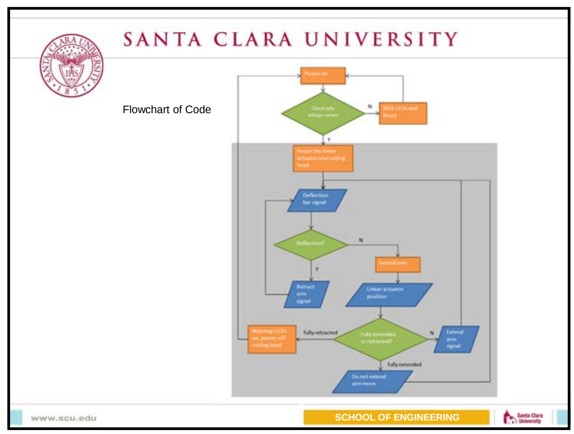
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Flowchart of Code
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Future Testing

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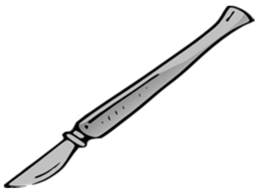
Cut Precision Test

- Purpose:
  - Measure the tightness of the AIRWT trimmer-head path about the vine or trellis post.



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Cart Speed Performance Evaluation

- Purpose
  - To evaluate its performance at various cart speeds in order to determine which the acceptable cart speeds will yield acceptable precision ranges, as denoted in the PDS.

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Competitive Analysis

	Force Sensor Assisted	Multiple Mounting Types	Removal Method	Standalone System	Function on Slopes	Estimated MSRP
AIRWT	Yes	No	Trim	Yes	Yes	$3,000
Falconero	Yes	No	Cultivate	No	No	$6,000
Weed Badger	Yes	Yes	Cultivate/Trim	No	No	$6,000
Kimco Mfg. Model 9300	Yes	Yes	Cultivate	No	No	$20,000
Pellenec Tournesol	No	Yes	Cultivate	No	No	$21,000

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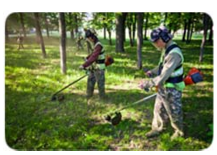
Competitive Analysis (cont.)



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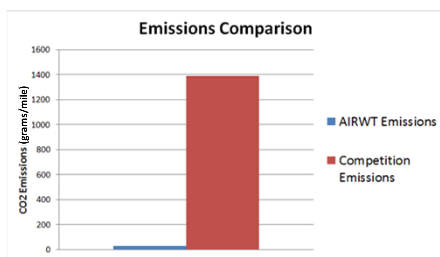
Proposed Advantages



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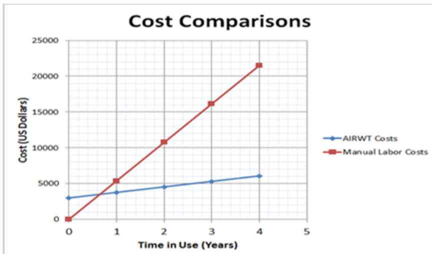
Proposed Advantages



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Moving Forward

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Year-end Goals

- Testing
- Reshape mounting plate
- Add linear actuator guides
- PID control

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What's Next?

- Major restrictions of a 9 month product development cycle
  - severe limitations on project scope
    - hence the omission of an autonomous mounting vehicle in this design iteration
- Develop a fully electric mounting vehicle
- Adapt system for different agricultural sectors

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What's Next? (cont.)

- Scale-up/scale-out for different sized operations
- Use of heavy-duty (industry-grade) materials
- Improved electronic capabilities
  - self-diagnosing
  - self-correcting
  - auto shut-off

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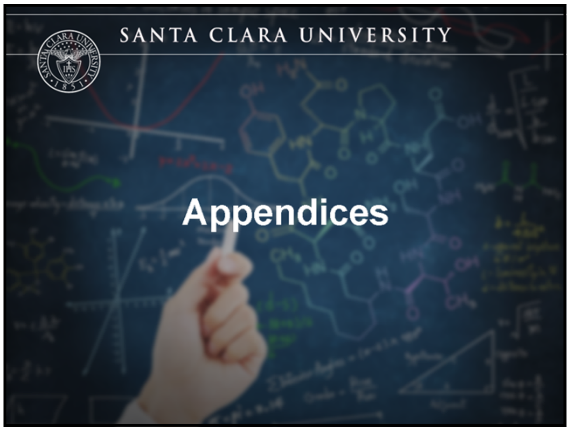
Questions? Comments?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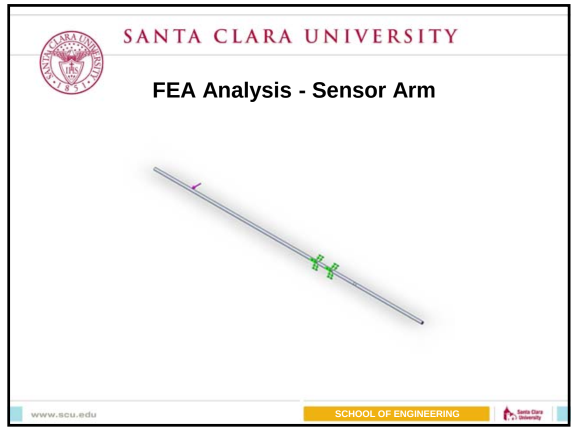
Appendices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FEA Analysis - Sensor Arm
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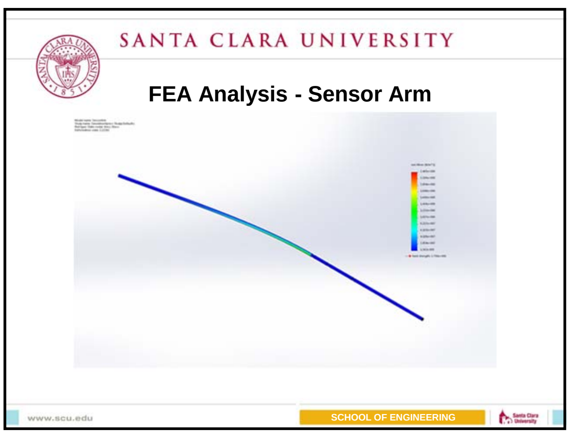
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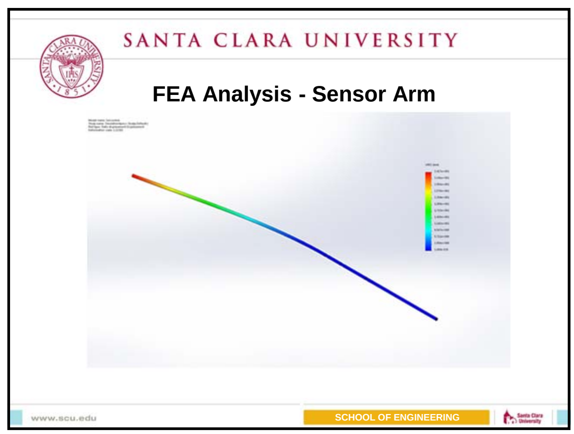
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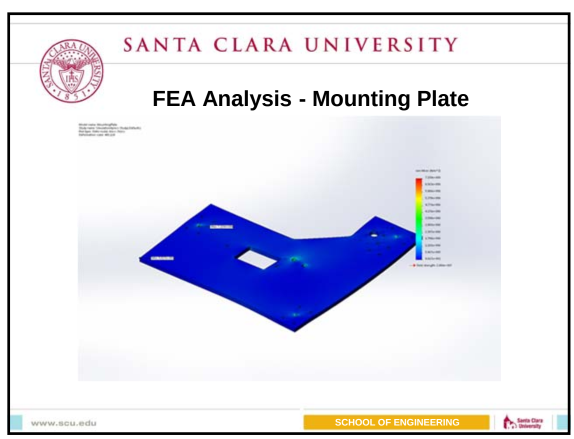
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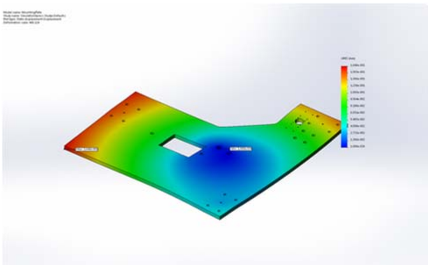
FEA Analysis - Mounting Plate



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$$q_1 = \theta$$
$$q_2 = y$$

$$T = \frac{1}{2} M v_{C.G.}^2 = \frac{1}{2} M \left[\dot{y}\hat{j} + \frac{L}{2}\dot{\theta}(\sin\theta\,\hat{j} - \cos\theta\,\hat{i}) \right] \circ \left[\dot{y}\hat{j} + \frac{L}{2}\dot{\theta}(\sin\theta\,\hat{j} - \cos\theta\,\hat{i}) \right]$$
$$= \frac{1}{2} M \left[\dot{y}^2 - L\dot{y}\dot{\theta}\sin\theta + \left(\frac{L}{2}\dot{\theta}\right)^2 (\sin^2\theta + \cos^2\theta) \right]$$
$$V = \frac{1}{2} k\theta^2$$
$$L = \frac{1}{2} M \left[\dot{y}^2 - L\dot{y}\dot{\theta}\sin\theta + \left(\frac{L}{2}\dot{\theta}\right)^2 \right] - \frac{1}{2} k\theta^2$$
$$\frac{\partial L}{\partial q_1} = -k\theta$$
$$\frac{\partial L}{\partial \dot{q}_1} = M\left[-\frac{L}{2}\dot{y}\sin\theta + \left(\frac{L}{2}\right)^2 \dot{\theta} \right]; \quad \frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}_1}\right) = M\left[-\frac{L}{2}(\ddot{y}\sin\theta + \dot{\theta}\dot{y}\cos\theta) + \left(\frac{L}{2}\right)^2 \ddot{\theta} \right]$$
$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}_1}\right) - \frac{\partial L}{\partial q_1} = Q_1$$
$$M\left[-R(\ddot{y}\sin\theta + \dot{\theta}\dot{y}\cos\theta) + (R)^2\ddot{\theta} \right] + k\theta = kr(t-\tau)$$

$$\frac{\partial L}{\partial q_2} = 0$$
$$\frac{\partial L}{\partial \dot{q}_2} = M\left(\dot{y} - \frac{L}{2}\dot{\theta}\sin\theta \right); \quad \frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}_2}\right) = M\left[\ddot{y} - \frac{L}{2}\ddot{\theta}\sin\theta - \frac{L}{2}\dot{\theta}\cos\theta \right]$$
$$\frac{d}{dt}\left(\frac{\partial L}{\partial \dot{q}_2}\right) - \frac{\partial L}{\partial q_2} = Q_2$$
$$M\left[\ddot{y} - R\ddot{\theta}\sin\theta - R\dot{\theta}\cos\theta \right] = 0$$

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SCHOOL OF ENGINEERING SENIOR DESIGN CONFERENCE
MAY 14, 2015

PROJECT EVALUATION FORM

Session: ***Mechanical Engineering 2***
Room #: ***Benson Center, Williman Room***

Judge's Name: Frank A.

Project Title: **Automated In-Row Weed Trimmer**
Group Members: Joshua Baculi, Gaston Young, Joshua Ding, Marit Knapp, Tyler Castrucci
Advisors: Timothy Hight, Christopher Kitts

Please evaluate senior engineering design projects and presentations using the following point system:

5 = Excellent (at the level of an entry-level engineer you would hire)
4 = Good (at the level of an accomplished college senior)
3 = Average (at the level typical of a college senior)
2 = Below Average (not up to the expectations for a college senior)
1 = Poor (significant errors or omissions)
N/A if no appropriate score applies

DESIGN PROJECT

A. Technical Accuracy 3
B. Creativity and Innovation 3
C. Supporting Analytical Work 3
D. Methodical Design Process Demonstrated 3
E. Addresses Project Complexity Appropriately 3
F. Expectation of Completion (by term's end) 3
G. Design & Analysis of tests 3
H. Quality of Response during Q&A 3

PRESENTATION

A. Organization 3
B. Use of Allotted Time 4
C. Visual Aids 3
D. Confidence and Poise 3

19 18

GRAND TOTAL (Sum of Design Project and Presentation Totals): 37

Please circle each of the following considerations that were addressed by the presentation:

economic, environmental, sustainability, manufacturability, ethical, health and safety, social, political

Comments (Optional): ______________________________

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MAY 14, 2015

PROJECT EVALUATION FORM

Session: ***Mechanical Engineering 2***
Room #: ***Benson Center, Williman Room***

Judge's Name: Collin Burdick

Project Title: **Automated In-Row Weed Trimmer**
Group Members: Joshua Baculi, Gaston Young, Joshua Ding, Marit Knapp, Tyler Castrucci
Advisors: Timothy Hight, Christopher Kitts

Please evaluate senior engineering design projects and presentations using the following point system:

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1 = Poor (significant errors or omissions)
N/A if no appropriate score applies

DESIGN PROJECT 30

A. Technical Accuracy	4	E. Addresses Project Complexity Appropriately	5
B. Creativity and Innovation	3	F. Expectation of Completion (by term's end)	3
C. Supporting Analytical Work	4	G. Design & Analysis of tests	3
D. Methodical Design Process Demonstrated	3	H. Quality of Response during Q&A	5

PRESENTATION 20

A. Organization	5	C. Visual Aids	5
B. Use of Allotted Time	5	D. Confidence and Poise	5

GRAND TOTAL (Sum of Design Project and Presentation Totals): 50

Please circle each of the following considerations that were addressed by the presentation:

economic environmental sustainability manufacturability
ethical health and safety social political

Comments (Optional): Great job discussing design constraints and setting expectations. I liked the visuals to put the design into perspective. Much of the system looks prone to failure (electrical w/ 3 batteries, actuator arm, wheels getting stuck). As this is a consumer product, you really needed to show more economic analysis

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MAY 14, 2015

PROJECT EVALUATION FORM

Session: ***Mechanical Engineering 2***
Room #: ***Benson Center, Williman Room***

Judge's Name: Jackie Edem

Project Title: **Automated In-Row Weed Trimmer**
Group Members: Joshua Baculi, Gaston Young, Joshua Ding, Marit Knapp, Tyler Castrucci
Advisors: Timothy Hight, Christopher Kitts

Please evaluate senior engineering design projects and presentations using the following point system:

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3 = Average (at the level typical of a college senior)
2 = Below Average (not up to the expectations for a college senior)
1 = Poor (significant errors or omissions)
N/A if no appropriate score applies

DESIGN PROJECT

A. Technical Accuracy 3
B. Creativity and Innovation 4
C. Supporting Analytical Work 3
D. Methodical Design Process Demonstrated 3
E. Addresses Project Complexity Appropriately 4
F. Expectation of Completion (by term's end) 3
G. Design & Analysis of tests 2
H. Quality of Response during Q&A 4

PRESENTATION

A. Organization 4
B. Use of Allotted Time 4
C. Visual Aids 3
D. Confidence and Poise ~~4~~ 3

GRAND TOTAL (Sum of Design Project and Presentation Totals): 40

Please circle each of the following considerations that were addressed by the presentation:

economic environmental sustainability manufacturability
ethical health and safety social political

Comments (Optional): Visuals need much more labeling/detail to understand what is being shown. Would have liked to see more testing and analysis.

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MAY 14, 2015

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PROJECT EVALUATION FORM

Session: ***Mechanical Engineering 2***
Room #: ***Benson Center, Williman Room***

Judge's Name: Chris Hintz

Project Title: **Automated In-Row Weed Trimmer**
Group Members: Joshua Baculi, Gaston Young, Joshua Ding, Marit Knapp, Tyler Castrucci
Advisors: Timothy Hight, Christopher Kitts

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3 = Average (at the level typical of a college senior)
2 = Below Average (not up to the expectations for a college senior)
1 = Poor (significant errors or omissions)
N/A if no appropriate score applies

DESIGN PROJECT

A. Technical Accuracy 4
B. Creativity and Innovation 4
C. Supporting Analytical Work 3
D. Methodical Design Process Demonstrated 3
E. Addresses Project Complexity Appropriately 4
F. Expectation of Completion (by term's end) 4
G. Design & Analysis of tests 3
H. Quality of Response during Q&A 3

PRESENTATION

A. Organization 4
B. Use of Allotted Time 4
C. Visual Aids 5
D. Confidence and Poise 4

GRAND TOTAL (Sum of Design Project and Presentation Totals): ~~47~~ $\boxed{45}$ ARW

Please circle each of the following considerations that were addressed by the presentation:

economic, environmental, sustainability, manufacturability
ethical, health and safety, social, political

Comments (Optional): Thank You and Good Luck!

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MAY 14, 2015

PROJECT EVALUATION FORM

Session: *Mechanical Engineering 2*
Room #: *Benson Center, Williman Room*

Judge's Name: Paul Kang

Project Title: **Automated In-Row Weed Trimmer**
Group Members: Joshua Baculi, Gaston Young, Joshua Ding, Marit Knapp, Tyler Castrucci
Advisors: Timothy Hight, Christopher Kitts

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4 = Good (at the level of an accomplished college senior)
3 = Average (at the level typical of a college senior)
2 = Below Average (not up to the expectations for a college senior)
1 = Poor (significant errors or omissions)
N/A if no appropriate score applies

DESIGN PROJECT

A. Technical Accuracy	4	E. Addresses Project Complexity Appropriately	3
B. Creativity and Innovation	3	F. Expectation of Completion (by term's end)	3
C. Supporting Analytical Work	3	G. Design & Analysis of tests	3
D. Methodical Design Process Demonstrated	3	H. Quality of Response during Q&A	4
	21		20

PRESENTATION

A. Organization	4	C. Visual Aids	3
B. Use of Allotted Time	4	D. Confidence and Poise	4

GRAND TOTAL (Sum of Design Project and Presentation Totals): 41

Please circle each of the following considerations that were addressed by the presentation:

economic environmental sustainability manufacturability
ethical health and safety social political

Comments (Optional): This needs more direct input from user. Farmers ~~like~~ want simple, rugged, easy to maintain equipment. ~~B~~ I don't think this meets the criteria

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PROJECT EVALUATION FORM

Session: ***Mechanical Engineering 2***
Room #: ***Benson Center, Williman Room***

Judge's Name: Giovanni Minelli

Project Title:	**Automated In-Row Weed Trimmer**
Group Members:	Joshua Baculi, Gaston Young, Joshua Ding, Marit Knapp, Tyler Castrucci
Advisors:	Timothy Hight, Christopher Kitts

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3 = Average (at the level typical of a college senior)
2 = Below Average (not up to the expectations for a college senior)
1 = Poor (significant errors or omissions)
N/A if no appropriate score applies

DESIGN PROJECT

A. Technical Accuracy	5
B. Creativity and Innovation	4
C. Supporting Analytical Work	4
D. Methodical Design Process Demonstrated	4
E. Addresses Project Complexity Appropriately	5
F. Expectation of Completion (by term's end)	5
G. Design & Analysis of tests	4
H. Quality of Response during Q&A	5

PRESENTATION

A. Organization	5
B. Use of Allotted Time	5
C. Visual Aids	5
D. Confidence and Poise	4

GRAND TOTAL (Sum of Design Project and Presentation Totals): 55

Please circle each of the following considerations that were addressed by the presentation:

economic, environmental, sustainability, manufacturability
ethical, health and safety, social, political

Comments (Optional): Interesting idea. Prototype seems like it may need lots of highly technical servicing, consider simplifying the design. Also add a rover!

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MAY 14, 2015

PROJECT EVALUATION FORM

Session: ***Mechanical Engineering 2***
Room #: ***Benson Center, Williman Room***

Judge's Name: Steven Schmitz

Project Title: **Automated In-Row Weed Trimmer** 2
Group Members: Joshua Baculi, Gaston Young, Joshua Ding, Marit Knapp, Tyler Castrucci
Advisors: Timothy Hight, Christopher Kitts

Please evaluate senior engineering design projects and presentations using the following point system:

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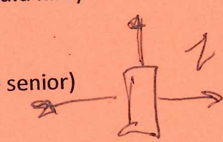
4 = Good (at the level of an accomplished college senior)
3 = Average (at the level typical of a college senior)
2 = Below Average (not up to the expectations for a college senior)
1 = Poor (significant errors or omissions)
N/A if no appropriate score applies



2 cutters?

DESIGN PROJECT

A. Technical Accuracy	5.	E. Addresses Project Complexity Appropriately	4.
B. Creativity and Innovation	4.	F. Expectation of Completion (by term's end)	4.
C. Supporting Analytical Work	4.	G. Design & Analysis of tests	4.
D. Methodical Design Process Demonstrated	4.	H. Quality of Response during Q&A	4

PRESENTATION

A. Organization	5.	C. Visual Aids	5.
B. Use of Allotted Time	4.	D. Confidence and Poise	4.

GRAND TOTAL (Sum of Design Project and Presentation Totals): 51

Please circle each of the following considerations that were addressed by the presentation:

economic　　environmental　　sustainability　　manufacturability

ethical　　health and safety　　social　　political

Comments (Optional): ______________________________

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MAY 14, 2015

PROJECT EVALUATION FORM

Session: ***Mechanical Engineering 2***
Room #: ***Benson Center, Williman Room***

Judge's Name: Don Van Buren

Project Title: **Automated In-Row Weed Trimmer**
Group Members: Joshua Baculi, Gaston Young, Joshua Ding, Marit Knapp, Tyler Castrucci
Advisors: Timothy Hight, Christopher Kitts

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3 = Average (at the level typical of a college senior)
2 = Below Average (not up to the expectations for a college senior)
1 = Poor (significant errors or omissions)
N/A if no appropriate score applies

DESIGN PROJECT

A. Technical Accuracy	5	E. Addresses Project Complexity Appropriately	4
B. Creativity and Innovation	5	F. Expectation of Completion (by term's end)	4
C. Supporting Analytical Work	5	G. Design & Analysis of tests	4
D. Methodical Design Process Demonstrated	5	H. Quality of Response during Q&A	5

PRESENTATION

A. Organization	5	C. Visual Aids	5
B. Use of Allotted Time	5	D. Confidence and Poise	3

GRAND TOTAL (Sum of Design Project and Presentation Totals): ~~54~~ $\boxed{55}$ ADW

Please circle each of the following considerations that were addressed by the presentation:

economic, environmental, sustainability, manufacturability
ethical, health and safety, social, political

Comments (Optional): ____________________

Appendix N

Concept Art

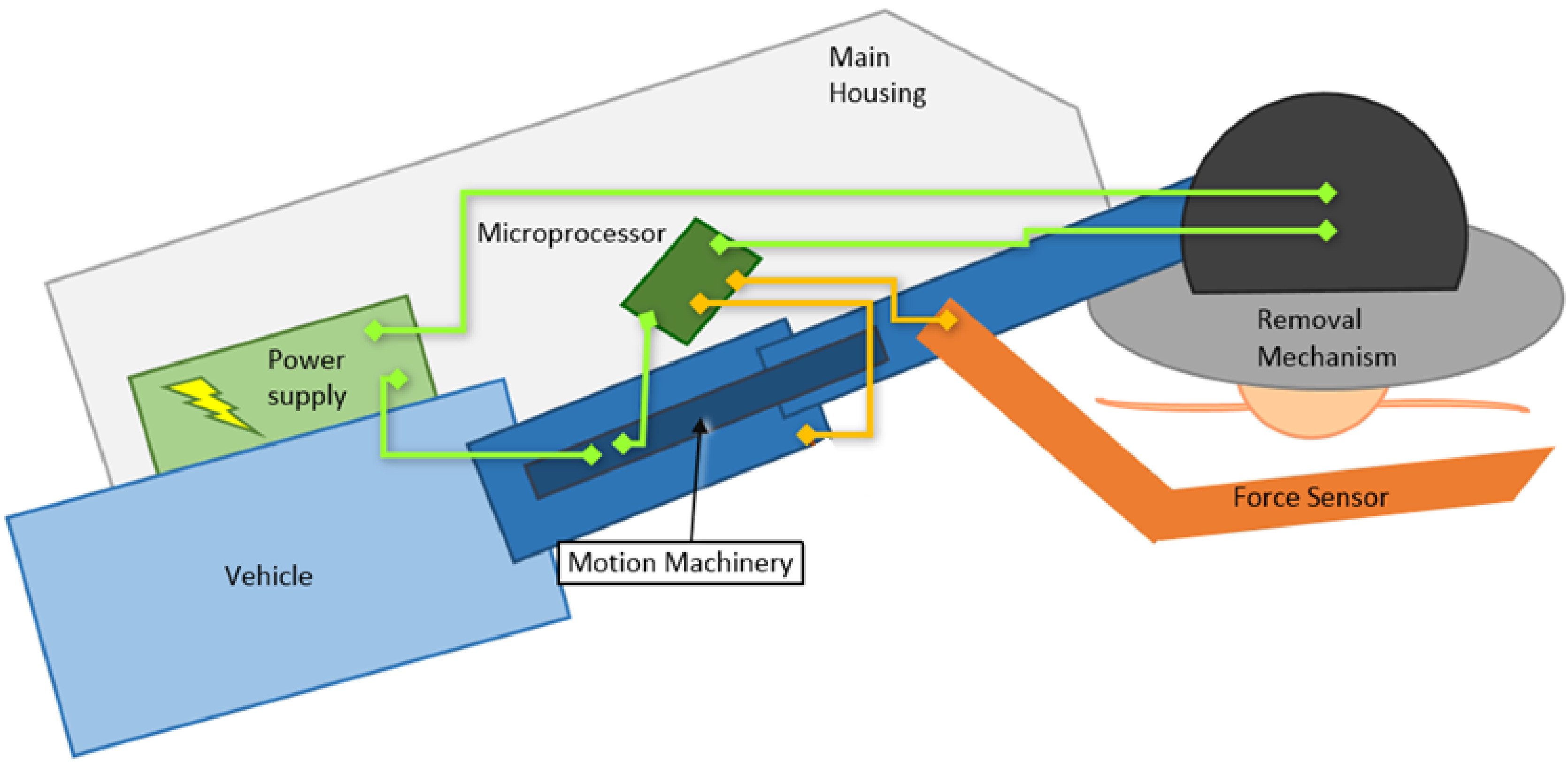


Figure N.1: General schematic of the AIRWT system.

Figure N.2: Early concept art for weed removal.

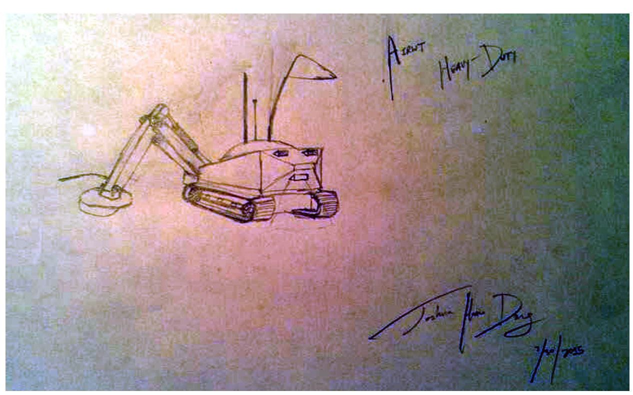
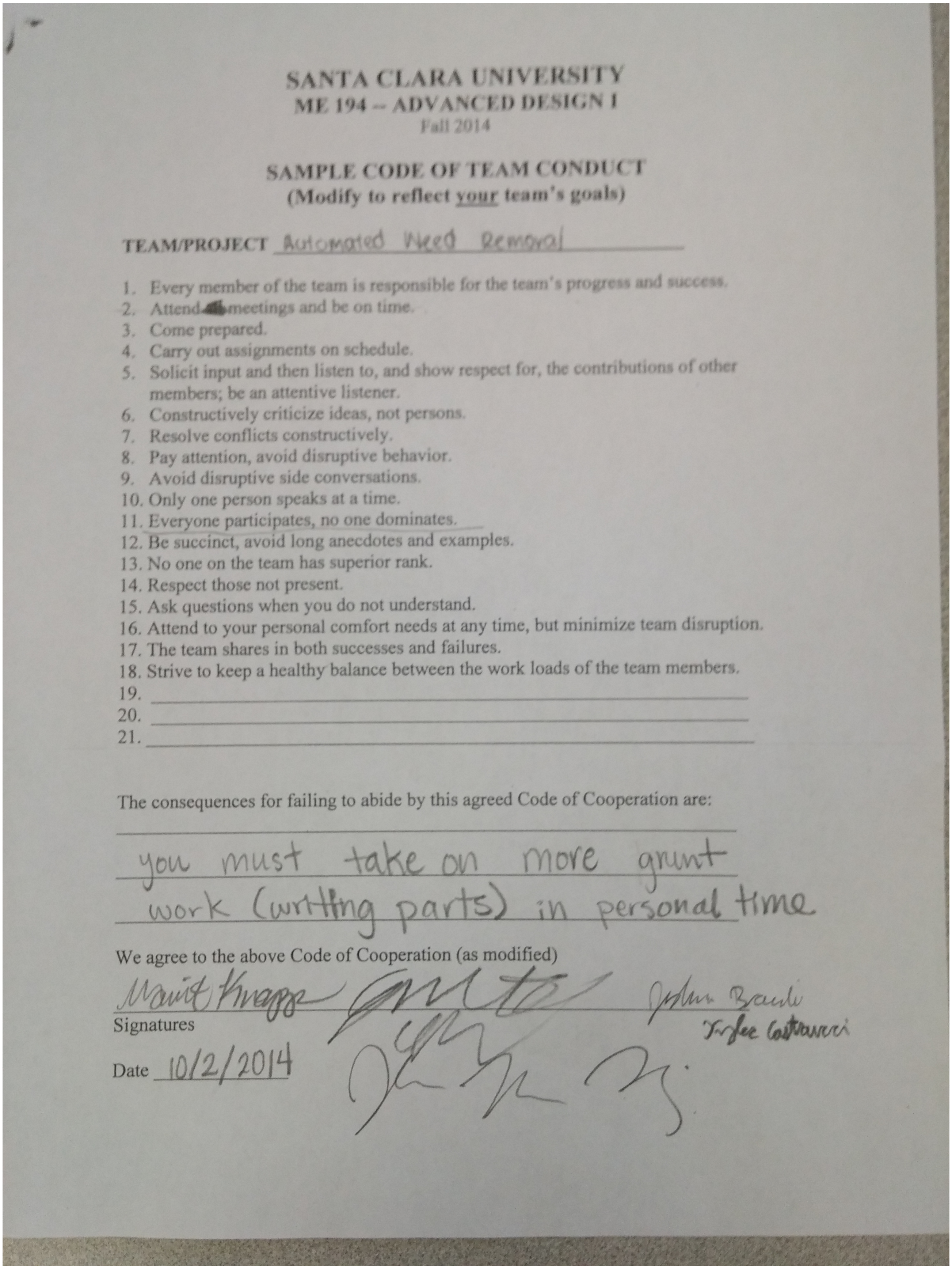


Figure N.3: Heavy duty system concept with autonomous mounting vehicle.

Appendix O

Team Documents



SANTA CLARA UNIVERSITY
ME 194 – ADVANCED DESIGN I
Fall 2014

SAMPLE CODE OF TEAM CONDUCT
(Modify to reflect your team's goals)

TEAM/PROJECT Automated Weed Removal

1. Every member of the team is responsible for the team's progress and success.
2. Attend ~~all~~ meetings and be on time.
3. Come prepared.
4. Carry out assignments on schedule.
5. Solicit input and then listen to, and show respect for, the contributions of other members; be an attentive listener.
6. Constructively criticize ideas, not persons.
7. Resolve conflicts constructively.
8. Pay attention, avoid disruptive behavior.
9. Avoid disruptive side conversations.
10. Only one person speaks at a time.
11. Everyone participates, no one dominates.
12. Be succinct, avoid long anecdotes and examples.
13. No one on the team has superior rank.
14. Respect those not present.
15. Ask questions when you do not understand.
16. Attend to your personal comfort needs at any time, but minimize team disruption.
17. The team shares in both successes and failures.
18. Strive to keep a healthy balance between the work loads of the team members.
19. ________
20. ________
21. ________

The consequences for failing to abide by this agreed Code of Cooperation are:

you must take on more grunt work (writing parts) in personal time

We agree to the above Code of Cooperation (as modified)

Signatures

Date 10/2/2014

Figure O.1: Beginning of project contract signed by team.